MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LII. FEBRUARY 12, 1892. No. 4

Lieut.-General J. F. TENNANT, C.I.E., R.E., F.R.S., President, in the Chair.

Bertram Bennett, B.A., Paignton, South Devon ;
Charles Bright, F.R.G.S., Assoc.M.Inst.C.E., M.I.E.E., Telegraph Works, Silvertown, Essex ;
Charles Burckhalter, Chabot Observatory, Oakland, California, and 962 Chester Street, Oakland ;
Arthur Hilton Molesworth, B.A., 15 Park Lane, W. ;
R. A. Sampson, B.A., St. John's College, Cambridge ;
Charles Daulman Webb, B.A., B.Sc., King's College School, and 112 Adelaide Road, South Hampstead, N.W.,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Louis Joyner, Bermuda (proposed by J. McCarthy) ;
Belgrave Ninnis, M.D., F.R.G.S., Deputy Inspector-General, Royal Navy, 46 Kensington Park Road, W. (proposed by Captain W. J. Ll. Wharton) ;
John Krom Rees, A.M , E.M., Director of the Observatory and Professor of Practical Astronomy and Geodesy, Columbia College, New York City (proposed by Professor A. W. Wright) ;
William James Watson, Gentleman, Morley House, South Stockton-on-Tees (proposed by Rev. W. Birks) ;
Elizabeth Brown, Further Barton, Cirencester (proposed by Captain W. Noble) ;
Alice Everett, M.A., 8 Gloucester Place, Greenwich, S.E., and Royal Observatory, Greenwich (proposed by A. M. W. Downing) ;
Annie Scott Dill Russell, 16 The Circus, Greenwich, S.E., and Royal Observatory, Greenwich (proposed by Edward W. Maunder).

Report of the Council to the Seventy-second Annual General Meeting of the Society.

The following table shows the progress and present state of the Society:—

	Compounders	Annual Subscribers	Mathematical Society	Total Fellows	Associates	Patron	Grand Total
December 31, 1890	239	374	3	616	48	1	665
Since elected	+11	+20	...	...	...	...	...
Deceased	−6	−5	...	...	−1	...	...
Resigned	−1	−9	...	...	...	...	...
Expelled	...	−9	...	...	...	...	...
Removals	+4	−4	...	...	...	...	...
December 31, 1891	247	367	3	617	47	1	665

Dr. Common's Account as Treasurer of the Royal

RECEIPTS.

	£	s.	d.	£	s.	d.
Balances, January 1, 1891 :—						
At Bankers', as per Pass Book	342	10	1			
Cheque not credited till 1891	2	2	0			
In hand of Assistant Secretary on account of Turnor and Horrox Fund	6	0	9			
In hand of Assistant Secretary on Petty Cash Account	3	17	1			
				354	9	11
Dividends on £13,200 Consols, 2¾ per cent. ...	353	18	8			
„ on £212 9 2 New 2½-per-cent. Stock. ...	2	11	10			
„ on £1,250 Metropolitan Stock, 3 per cent.	36	11	4			
Interest on £200 on deposit at Bankers'	1	17	5			
				394	19	3
Received on account of Subscriptions :—						
Arrears	184	7	0			
254 Annual Contributions for 1891	533	8	0			
5 „ „ 1892	10	10	0			
34 Admission Fees	71	8	0			
21 First Contributions	33	12	0			
				833	5	0
17 Composition Fees				357	0	0
Sales of Publications :—						
At Williams & Norgate's, 1890	25	3	0			
At Society's Rooms, 1891	45	14	6			
				70	17	6

Audited and found correct, 1892 Jan. 6.

ROBT. J. LECKY,
W. H. MAW.

£2,010 11 8

Astronomical Society, from January 1 to December 31, 1891.

EXPENDITURE.

	£	s.	d.	£	s.	d.
Assistant Secretary: Salary	250	0	0			
„ „ for assistance in editing Society's Publications ...	50	0	0			
				300	0	0
Income Tax and House Duty	10	10	0			
Fire Insurance	7	16	6			
				18	6	6
Printing, &c.	557	0	0			
Engraving and Lithography	6	17	6			
				563	17	6
Computation of Ephemerides				50	0	0
Turnor and Horrox Fund: Purchases for Library	8	1	6			
Encyclopædia Britannica	27	15	0			
Binding Books in Library	9	17	0			
				45	13	6
Alterations, Decorating, and Repairs	26	5	6			
Sundry Fittings and Repairs	12	12	11			
				38	18	5
Lantern, &c., for Evening Meetings	34	2	0			
Ballot-boxes	7	15	6			
Re-covering and repairing Globes	5	16	0			
Lantern-slides	2	4	0			
				49	17	6
House Expenses	53	12	8			
Wages	44	8	0			
Postage	70	18	3			
Carriage of Parcels	1	7	2			
Stationery and Office Expenses	9	1	2			
Expenses of Meetings	20	0	0			
Coals and Gas	53	17	11			
Electric Lighting Expenses	1	13	4			
Rental of Wire for Time Signal, &c.	6	11	6			
Care of Fire-extinguishing Apparatus	3	8	9			
Sundries	5	4	0			
				270	2	9
Mrs. Jackson Gwilt's Annuity	8	19	0			
Lee and Janson Fund Grants	12	10	0			
				21	9	0
Purchase of £212 9 2 New 2½-per-cent. Stock at 94, including Commission				200	0	0
Bankers' Deductions on Cheques				0	1	11
Balances, December 31, 1891:—						
At Bankers', on current account	243	17	6			
„ „ on deposit	200	0	0			
In hand of Assistant Secretary on account of Turnor and Horrox Fund	7	19	3			
In hand of Assistant Secretary on Petty Cash Account		7	10			
				452	4	7
				£2,010	11	8

Assets and Present Property of the Society, 1892 January 1.

	£	s.	d.	£	s.	d.
Balances, December 31, 1891:—						
At Bankers', on current account	243	17	6			
„ „ on deposit	200	0	0			
In hand of Assistant Secretary on account of Turnor and Horrox Fund	7	19	3			
In hand of Assistant Secretary on Petty Cash Account	0	7	10			
				452	4	7
Due on account of Subscriptions:—						
1 Contribution of 4 years' standing	8	8	0			
7 Contributions of 3 „	44	2	0			
36 „ 2 „	151	4	0			
65 „ 1 „	136	16	0			
	340	10	0			
Less 5 Contributions paid in advance ...	10	10	0			
				330	0	0
Due from Messrs. Williams & Norgate for sales of Publications during 1891				25	12	2
Due from Messrs. Wesley & Son, from sale of old non-astronomical books				12	18	0
£13,200 $2\frac{3}{4}$-per-cent. Consols, including the Lee and Janson Fund, the Turnor Fund, the Horrox Memorial Fund, and Mrs. Jackson Gwilt's gift.						
£212 9 2 New $2\frac{1}{2}$-per-cent. Consols.						
£1,250 Metropolitan 3-per-cent. Stock.						
Astronomical and other Manuscripts, Books, Prints, and Instruments; Furniture.						
Unsold Publications of the Society.						
5 Gold Medals.						

Trust Funds.

The Turnor Fund: A sum of 450*l.* 2¾-per-cent. Consols, the interest to be used in the purchase of books for the Library.

The Horrox Memorial Fund: A sum of 100*l.* 2¾-per-cent. Consols, the interest to be used in the purchase of books for the Library.

The Lee and Janson Fund: A sum of 323*l.* 16*s.* 3*d.* 2¾-per-cent. Consols, the interest to be given by the Council to the widow or orphan of any deceased Fellow or Associate of the Society who may stand in need of it.

Mrs. Jackson Gwilt's Gift: 300*l.* 2¾-per-cent. Consols, subject to an annuity to the donor during her life of 8*l.* 19*s.* per annum.

Report of the Auditors.

We have examined the Treasurer's accounts for the year 1891, and have found and certified the same to be correct. The cash in hand on Dec. 31, 1891, including the balance at the bankers' on current account, and a sum of 200*l.* on deposit, amounted to 452*l.* 4*s.* 7*d.*

The funded property of the Society has been increased by the purchase of 212*l.* 9*s.* 2*d.* New 2½-per-cent. stock.

The books, instruments, and other effects have been examined, and they appear to be in a satisfactory condition.

We have laid on the table a list of the names of those Fellows who are in arrear for sums due at the last Annual General Meeting, with the amount due against each Fellow's name.

Robt. J. Lecky,
W. H. Maw.

Stock in hand of volumes of the *Memoirs*:—

Vol.	At Society's Rooms	At Williams & Norgate's	Vol.	At Society's Rooms	At Williams & Norgate's
I. Part 1	7	...	XXX.	157	1
I. Part 2	42	...	XXXI.	140	...
II. Part 1	54	...	XXXII.	151	1
II. Part 2	20	...	XXXIII.	161	...
III. Part 1	65	1	XXXIV.	162	4
III. Part 2	84	1	XXXV.	107	5
IV. Part 1	77	3	XXXVI.	195	8
IV. Part 2	90	3	XXXVII. Part 1	337	8
V.	102	3	XXXVII. Part 2	283	8
VI.	121	3	XXXVIII.	268	1
VII.	142	3	XXXIX. Part 1	239	4
VIII.	126	3	XXXIX. Part 2	243	3
IX.	133	3	XL.	260	...
X.	143	...	XLI.	408	2
XI.	152	...	XLII.	232	3
XII.	159	...	XLIII.	235	2
XIII.	161	...	XLIV.	217	...
XIV.	365	2	XLV.	246	...
XV.	137	...	XLVI.	228	1
XVI.	163	...	XLVII. Part 1	3	...
XVII.	146	1	XLVII. Part 2	18	...
XVIII.	140	...	XLVII. Part 3	2	...
XIX.	147	...	XLVII. Part 4	10	...
XX.	139	...	XLVII. Part 5	10	...
XXI. Part 1	312	...	XLVII. Part 6	10	...
XXI. Part 2	98	...	XLVII.	209	1
XXI. 1 & 2 (together)	59	...	XLVIII. Part 1	248	3
XXII.	162	...	XLVIII. Part 2	258	2
XXIII.	145	...	XLIX. Part 1	471	2
XXIV.	153	...	XLIX. Part 2	201	4
XXV.	163	...	Index to *Memoirs*	644	...
XXVI.	170	...			
XXVII.	421	...			
XXVIII.	380	...			
XXIX.	398	1			

Stock in hand of volumes of the *Monthly Notices* :—

Vol.	At Society's Rooms	At Williams & Norgate's	Vol.	At Society's Rooms	At Williams & Norgate's
I.	63	...	XXVII.	4	...
II.	65	...	XXVIII.	72	...
III.	...	...	XXIX.	52	...
IV.	...	...	XXX.	65	2
V.	...	...	XXXI.	93	...
VI.	50	...	XXXII.	115	5
VII.	2	...	XXXIII.	97	...
VIII.	153	1	XXXIV.	75	1
IX.	24	3	XXXV.	58	...
X.	178	1	XXXVI.	31	1
XI.	184	1	XXXVII.	38	3
XII.	106	2	XXXVIII.	101	2
XIII.	178	3	XXXIX.	97	1
XIV.	177	3	XL.	112	3
XV.	169	2	XLI.	111	5
XVI.	154	2	XLII.	120	1
XVII.	167	1	XLIII.	117	2
XVIII.	245	...	XLIV.	123	3
XIX.	57	...	XLV.	122	2
XX.	30	...	XLVI.	117	2
XXI.	17	...	XLVII.	135	5
XXII.	33	...	XLVIII.	127	3
XXIII.	19	...	XLIX.	121	11
XXIV.	24	...	L.	125	13
XXV.	15	...	LI.	123	17
XXVI.	11	...	Index ...	564	3

Library Catalogue 574

In addition to the above volumes of the *Monthly Notices*, the Society has a considerable stock of separate numbers of nearly all the volumes. With the exception, however, of Vols. XXXVI. to LI. no complete volumes can be formed from the separate numbers in stock.

Instruments belonging to the Society.

No. 1. The *Harrison* clock.
„ 2. The *Owen* portable circles, by Jones.
„ 3. The *Beaufoy* circle.

No. 4. The *Beaufoy* transit instrument.
„ 5. The *Herschel* 7-foot telescope.
„ 6. The *Greig* universal instrument, by Reichenbach and Ertel. The transit telescope, by Utzschneider and Fraunhofer, of Munich.
„ 7. The *Smeaton* equatoreal.
„ 8. The *Cavendish* apparatus.
„ 9. The 7-foot Gregorian telescope (late Mr. Shearman's).
„ 10. The variation transit instrument (late Mr. Shearman's).
„ 11. The universal quadrat, by Abraham Sharp.
„ 12. The *Fuller* theodolite.
„ 13. The standard scale, by Troughton and Simms.
„ 14. The *Beaufoy* clock, No. 1.
„ 15. The *Beaufoy* clock, No. 2.
„ 16. The *Wollaston* telescope.
„ 17. The *Lee* circle.
„ 18. The *Sharpe* reflecting circle.
„ 19. The *Brisbane* circle.
„ 20. The *Baker* universal equatoreal.
„ 21. The *Reade* transit.
„ 22. The *Matthew* equatoreal, by Cooke.
„ 23. The *Matthew* transit instrument.
„ 24. The *South* transit instrument.
„ 25. A sextant, by Bird (formerly belonging to Captain Cook).
„ 26. A globe showing the precession of the equinoxes.
The *Sheepshanks* collection :—
„ 27. (1) 30-inch transit instrument, by Simms, with level and two iron stands.
„ 28. (2) 6-inch transit theodolite, with circles divided on silver; reading microscopes, both for altitude and azimuth; cross and siding levels; magnetic needle; plumb-line; portable clamping foot and tripod stand.
„ 29. (3) Equatorial stand and clock movement for $4\frac{6}{10}$-inch telescope (telescope lost); double-image micrometer; two wire micrometers; object-glass micrometer.
„ 30. (4) $3\frac{1}{4}$-inch achromatic telescope, with equatorial stand; double-image micrometer; one terrestrial and three astronomical eyepieces.
„ 31. (5) $2\frac{3}{4}$-inch achromatic telescope, with stand; one terrestrial and three astronomical eyepieces.
„ 33. (7) 2-foot navy telescope.
„ 34. (8) Transit instrument of 45 inches focal length, with iron stand and also Ys for fixing to stone piers; two axis levels.
„ 35. (9) Repeating theodolite, by Ertel, with folding tripod stand.

No. 36. (10) 8-inch pillar sextant, by Troughton, divided on platinum, with counterpoise stand and artificial horizon.

„ 37. (11) Portable zenith telescope and stand, $2\frac{3}{4}$-inch aperture and 26 inches focal length; 10-inch horizontal circle and 8-inch vertical circle, read to 10″ by two verniers to each circle.

„ 38. (12) 18-inch Borda repeating circle, by Troughton, $2\frac{1}{8}$-inch aperture and 24 inches focal length; the circles divided on silver, the horizontal circle being read by four verniers, and the vertical circle by three verniers, each to 10″.

„ 39. (13) 8-inch vertical repeating circle, with diagonal telescope, by Troughton and Simms; circle divided on silver, reading to 10″; a 5-inch circle at eye-end, reading to single minutes; horizontal circle 9 inches diameter in brass, reading to single minutes.

„ 40. (14) A set of surveying instruments, consisting of a 12-inch theodolite for horizontal angles only, reading to 10″; two sets of adjusting plates; tripod stand with enclosed telescope; heavy stand for theodolite; Y piece of level; two large and three small ground-glass bubbles divided; level collimator, object-glass $1\frac{5}{8}$-inch diameter and 16 inches focal length; micrometer eyepiece, comb, and wires; mercury bottle and trough.

„ 41. (15) Level collimator, with object-glass $1\frac{7}{8}$-inch diameter and 16 inches focal length; stand, rider-level, and fittings.

„ 42. (16) 10-inch reflecting circle by Troughton, reading by three verniers to 20″; counterpoise stand; artificial horizon, with mercury; two tripod stands.

„ 43. (17) Hassler's reflecting circle, by Troughton, with counterpoise stand.

„ 44. (18) 6-inch reflecting and repeating circle, by Troughton and Simms, contained in three boxes, two of which form stands. Circle divided on silver, reading to single minutes; two inside arcs divided to single degrees, 150 degrees on each side; artificial horizon and mercury.

„ 45. (19) 5-inch reflecting and repeating circle, by Lenoir, of Paris.

„ 46. (20) Reflecting circle, by Jecker, of Paris, 11 inches in diameter, with one vernier reading to 15″.

„ 47. (21) Box sextant; reflecting plane and level.

„ 48. (22) Prismatic compass, by Troughton and Simms.

„ 49. (23) Mountain barometer.

„ 50. (24) Prismatic compass, by Thomas Jones, mounted with a cylindrical lens.

No. 51. (25) Ordinary $4\frac{1}{2}$-inch compass with needle.
,, 52. (26) Dipping needle, by Robinson.
,, 53. (27) Compass needle, mounted for variation.
,, 54. (28) Magnetic intensity needle, by Meyerstein, of Göttingen; a strongly fitted brass box with heavy magnet; filar suspension.
,, 55. (29) Box of magnetic apparatus.
,, 56. (30) Hassler's reflecting circle, by Troughton; a $10\frac{1}{2}$-inch reflecting and repeating circle, with stand and counterpoise, divided on platinum with two movable and two fixed indices; four verniers reading to 10″.
,, 57. (31) Box sextant and glass plane artificial horizon, by Troughton and Simms.
,, 58. (32) Plane $2\frac{3}{8}$-inch speculum, artificial horizon, and stand.
,, 59. (33) $2\frac{1}{2}$-inch circular level horizon, by Dollond.
,, 60. (34) Artificial horizon, roof, and trough; the trough $8\frac{1}{4}$ by $4\frac{1}{2}$ inches; tripod stand.
,, 61. (35) Set of drawing instruments, consisting of 6-inch circular protractor and common protractor, T-square; one beam compass.
,, 62. (36) A pantograph.
,, 63. (37) A noddy.
,, 64. (38) A small Galilean telescope with object-glass of rock crystal.
,, 65. (39) Five levels.
,, 66. (40) 18-inch celestial globe.
,, 67. (41) Varley stand for telescope.
,, 69. (43) Telescope, with object-glass of rock crystal.
,, 71. Portable altazimuth tripod.
,, 72. Four polarimeters.
,, 74. Registering spectroscope, with one large prism.
,, 76. Two five-prism direct-vision spectroscopes.
,, 78. $9\frac{1}{4}$-inch silvered-glass reflector and stand, by Browning.
,, 79. Spectroscope.
,, 80. A small box, containing three square-headed Nicol's prisms; two Babinet's compensators; two double-image prisms; three Savarts; one positive eyepiece, with Nicol's prism; one dark wedge.
,, 81. A back-staff, or Davis' quadrant.
,, 82. A nocturnal or star dial.
,, 83. An early non-achromatic telescope, of about 3 feet focal length, in oak tube, by Samuel Scatliffe, London.
,, 84. A Hollis observing chair.
,, 85. Double-image micrometer, by Troughton and Simms.
,, 86. $4\frac{1}{2}$-inch Gregorian reflecting telescope, by Short, with altazimuth stand and 6-inch altitude and azimuth circles and two eyepieces.

No. 87. $3\frac{1}{4}$-inch Gregorian reflecting telescope with wooden tripod stand.
,, 88. Pendulum, with 5-foot brass suspension rod, working on knife-edges, by Thomas Jones.
,, 89. A Rhabdological Abacus. A contrivance invented by Mr. H. Goodwyn, consisting of a box filled with compartments, in which are square rods covered with numbers, which can be arranged so as to facilitate the labour of multiplying high numbers.
,, 90. An Arabic celestial globe of bronze, $5\frac{3}{4}$ inches in diameter.
,, 91. Astronomical time watchcase, by Professor Chevallier.
,, 92. 2-foot protractor, with two movable arms, and vernier.
,, 93. Beam compass, in box.
,, 94. 2-foot navigation scale.
,, 95. Stand for testing measures of length.
,, 96. Artificial planet and star, for testing the measurement of a fixed distance at different position-angles.
,, 97. 12-cell Leclanché battery.
,, 98. 2-foot 6-inch navy telescope, with object-glass $2\frac{1}{2}$ inches, by Cooke, with portable wooden tripod stand.
,, 99. 12-inch transit instrument, by Fayrer and Son, with level and portable stand.
,, 100. 9-inch transit instrument, with level and iron stand.
,, 101. Small equatorial sight instrument, by G. Adams, London.
,, 102. Sun-dial, by Troughton.
,, 103. Sun-dial, by Casella.
,, 104. Sun-dial.
,, 105. Box sextant, by Troughton and Simms.
,, 106. Prismatic compass, by Schmalcalder, London.
,, 107. Compass, by C. Earle, Melbourne.
,, 108. Prismatic compass, by Negretti and Zambra.
,, 109. Dipleidoscope, by E. Dent.
,, 110. Abney level, by Elliott.
,, 111. Pocket spectroscope, by Browning.
,, 112. Universal sun-dial.
,, 113. Double sextant, by Jones.
,, 114. Two models, illustrating the effects of circular motions.
,, 115. A cometarium.
,, 116. A pair of 18-inch globes.
,, 117 } Two old sun-dials.
,, 118 }

No. 119. Specimens of diffraction gratings, by Prof. W. A. Rogers.
,, 120. A 6-prism spectroscope, by Browning.
,, 121. Spitta's improved maximum and minimum thermometer.
,, 122. A 6-inch speculum, with flat; the speculum said to be by Sir W. Herschel, and re-figured by Sir J. Herschel.
,, 123. A 6-inch refracting telescope, by Grubb, with 3 eyepieces.
,, 124. Position micrometer, by Cooke.
,, 125. A 6-inch refracting telescope, by Simms, with eyepieces and solar diagonal.
,, 126. $3\frac{1}{2}$-in. portable refracting telescope, by Tulley, with tripod stand.
,, 127. Globe representing the visible surface of the Moon, by John Russell, R.A. (1797).
,, 128. Bichromate battery and Ruhmkorff coil.
,, 129. Slater's improved armillary sphere, presented by Prof. Slater.

The following instruments are lent, during the pleasure of the Council, to the undermentioned persons :—

No. 4. The *Beaufoy* transit instrument, to the Observatory, Kingston, Canada.
,, 10. Variation transit, to Mr. Maxwell Hall.
,, 16. The *Wollaston* telescope, to Mr. R. Inwards.
,, 22. The *Matthew* equatoreal, to Mr. J. Brett.
,, 23. The *Matthew* transit, to Captain W. Noble.
,, 28. (2) 6-inch theodolite and stand, to Dr. A. A. Common.
,, 29. Wire micrometer (No. 1), to Mr. C. Thwaites.
,, ,, Wire micrometer (No. 2), to Mr. Maxwell Hall.
,, 30. (4) $3\frac{1}{4}$-inch equatoreal and stand, to Mr. E. B. Powell.
,, ,, ,, Double-image micrometer, to Mr. Maxwell Hall.
,, 31. (5) $2\frac{3}{4}$-inch telescope and stand, to Mr. F. J. Wardale.
,, 34. (8) Transit instrument and stand, to Professor C. Pritchard.
,, 38. (12) 18-inch *Borda* repeating circle, to Mr. Maxwell Hall.
,, 39. (13) 8-inch repeating circle, to Mr. J. Norman Lockyer.
,, 42. (16) Artificial horizon, roof, and mercury bottle, to Mr. C. Thwaites.
,, 50. (24) Prismatic compass, to Mr. Maxwell Hall.
,, 52. (26) Dipping needle, to Mr. Maxwell Hall.
,, 54. (28) Magnetic intensity needle, to Mr. Maxwell Hall.
,, 69. (43) Telescope, with rock-crystal object-glass, to Dr. W. Huggins.
,, 78. $9\frac{1}{4}$-inch reflector and stand, to Mr. Maxwell Hall.
,, 79. Spectroscope, to Mr. Maxwell Hall.

No. 86. $4\frac{1}{2}$-inch Gregorian reflector, by Short (two mirrors only), to Dr. A. A. Common.

„ 99. 12-inch portable transit instrument, to Mr. H. T. Vivian.

„ 120. 6-prism spectroscope, by Browning, to Mr. C. Thwaites.

„ 123. 6-inch refractor, by Grubb, with three eyepieces, to Mr. W. E. Wilson.

„ 124. Position micrometer, by Cooke, and dark wedge, to the Rev. A. Freeman.

The Gold Medal.

The Council have awarded the Society's Gold Medal to Professor G. H. Darwin for his work on Tides and their influence on the figures and motions of the Heavenly Bodies. The President will lay before the Society the grounds upon which the award has been founded.

Obituary.

The Council regret that they have to record the loss by death of the following Fellows and Associate during the past year:—

Fellows:—Prof. J. C. Adams.
Sir G. B. Airy.
Joseph Beck.
H. L. Boulton.
Dr. F. E. Brünnow.
Captain W. Chimmo.
Charles O. Dayman.
Albert Escott.
T. H. Hovenden.
Thomas Lee.
John Merrifield.
J. S. Nimkey.
N. R. Pogson.
Henry Pratt.
Benjamin Scott.
Lieut. Sidney G. Smith.
E. W. Snell.

Associate:—Eduard Schönfeld.

The obituary notice of the late Prof. J. C. Adams is deferred to the next Annual Report.

George Biddell Airy was born at Alnwick on 1801 July 27. He came of a stock whose home is in Kentmere, Westmoreland, where the Airys and Gilpins live to this day; and there is a record of the marriage at Kentmere of an Airy with a Gilpin in the fourteenth century. The particular branch from which George Biddell Airy sprang had, however, not lived in Westmoreland for some generations. His father, William Airy, was a Lincolnshire man, and somewhat late in life, at the age of about 50, had married Ann Biddell, of Playford, near Ipswich. There were three other children of this marriage, one of whom died in infancy. William Airy had a minor Government appointment, which took him into different parts of the country, and it was during a stay of three years at Alnwick that George was born. He went to school at Here-

ford, and afterwards to the Colchester Grammar School, and quite early manifested great ability, although in later life he would tell quaint stories which hinted that his sympathies were not entirely with the school curriculum. It may be that he learnt things more useful to him in his subsequent career in rambling about the farm at Playford, where his uncle, Arthur Biddell, insisted on his spending not only all his holidays but some considerable portion of the year as well. But his work at school was, at any rate, so exceptional that his uncle determined to send him to Cambridge, financial troubles having put this out of the power of his parents. He matriculated at Trinity College as a sizar on 1819 November 13, and after a brilliant career as an undergraduate, in the course of which he was elected Scholar of Trinity, he graduated as Senior Wrangler in 1823. There does not seem to have been any doubt from the first as to his outdistancing all the men of his year, although from his second term he supported himself by taking pupils in addition to his own work. He was elected a Fellow of Trinity College in 1824.

While still an undergraduate, Airy had contributed a paper to the Cambridge Philosophical Society on reflecting telescopes. This society had only been in existence about three years, having been founded, according to Prof. Sedgwick, by Dr. E. D. Clarke, Professor of Mineralogy; although the "first idea" was probably due to Sedgwick himself, who, while taking a tour in the Isle of Wight early in 1819 with Mr. Henslow, "deplored the want of some place in Cambridge to which those interested in science might resort with the certainty of meeting persons of similar or kindred tastes, and where they might learn what was being done abroad." * Airy's first paper, soon to be followed by a brilliant series, was received on 1822 November 25, and is printed in the second volume of the *Transactions*. Silvered glass meant in those days apparently always glass silvered at the back: and Airy shows how the double combination of lens and mirror in a Cassegrain telescope may be used to correct both chromatic and spherical aberration. In practice the idea does not seem to have been very successful, for he candidly confesses that on trying two 4-inch Cassegrain telescopes which he had constructed, "from some cause with which he was unacquainted, the image of a star or planet is surrounded with radiations which make the telescope quite useless for practical purposes." His next paper was read on 1824 March 15, after taking his degree, and he finds that the attraction of *Saturn's* ring should produce a flattening of the planet between the pole and the equator, which did not accord with the observations of Sir John Herschel. This was almost immediately followed by a beautifully simple investigation of the achromatism of eyepieces and microscopes. Such predecessors as Euler and Boscovich had practically made no advance towards the solution of this

* *Proc. Camb. Phil. Soc.* vol. vii. p. 2.

problem, and the subject had lain untouched for forty years; and yet the method explained by Airy in a few lines is so simple that it seems incredible that it should be so long overlooked. Three years later he returned to the theory of eyepieces and discussed their spherical aberration, and again showed his great power of "going to the root of the matter," to use a colloquial phrase with which his friends are familiar. He points out that the effects of spherical aberration are three: distortion of the object, curvature of the field, and bad definition away from the centre; and specifies three corresponding problems to be solved. A table at the end of the paper of practical rules for making eyepieces is also noteworthy.

He had written other papers showing great ability; one on Astigmatism, which he discovered in one of his own eyes, is of considerable importance. He suggested a perfectly successful method of correcting it by using a concave lens, one of whose surfaces, or both, were cylindrical; and this eminently practical suggestion involved him in a great mass of correspondence. Another paper contains some very pretty geometry of roulettes, to determine the proper shape for the teeth of cog-wheels, and appears to have been the first clear exposition of the important practical principles now universally recognised; and there are others on the figure of the Earth.

In 1826 the Lucasian professorship became vacant, and Airy was elected to it on 1826 December 7, so near the end of the year that in the Cambridge Calendar for 1828 the date of his election is given as 1827, though this is corrected in all other calendars. The successors of Barrow and Newton seemed to have gradually arrived at a somewhat liberal interpretation of their duties, though there are indications of a revival of activity just before Airy's time. In the calendar for 1802 we read, "No public lectures are delivered, but the (Lucasian) Professor is at all times accessible to students of any college, by whom he is frequently consulted." In 1826, however, and for some years previously, we find that "The Lucasian Professor gives a course of Mathematical lectures gratis." On Airy's appointment this becomes "The present Professor gives a course of experimental lectures," the fame of which has lasted to the present day; although the course was not many times repeated, for on 1828 February 6, Airy was made Plumian Professor of Astronomy and Experimental Philosophy, and Director of the new Observatory. It is curious that within a few years two men should have rapidly exchanged the one of these professorships for the other; for Woodhouse was elected to the Lucasian chair in 1820 and to the Plumian in 1822. The observatory was, doubtless, the attraction to both Woodhouse and Airy, although in 1822 it was only being built. The history of its foundation is thus told in the calendars of this period:

"A very general opinion having been entertained that it would greatly add to the utility and splendour of this University,

and might essentially promote the cause of science, to erect an observatory on the most approved plan, to be furnished with the best instruments that can be procured, measures were adopted, in 1820, to carry this idea into execution. The first step taken was to procure subscriptions from members of the University, and others, and by this means upwards of 6,000*l.* was obtained; a further addition to this sum was made by a Grace of the Senate 1820 May 5, by which 5,000*l.* was granted from the public chest in aid of this design." 4,000*l.* was added by a Grace 1824 June 4, and 3,115*l.* by a Grace 1824 December 8, according to the calendar for 1830. "At the same time regulations were made by which it was resolved that the superintendence and management of the observatory should be vested in the Plumian Professor, under whose direction two assistant observers should be placed." The assistants were to be graduates of the University, at salaries of 150*l.* and 100*l.*; and their duties were to consist principally in making meridional observations of the Sun, Moon, and fixed stars. It was further resolved "That the observations so made should each year, under the care of the Observer and his assistants, be printed and published at the expense of the University, and copies of the same presented to the principal observatories of Europe, viz.: Greenwich, Oxford, Dublin, Paris, Palermo. That in addition to the capital instruments of the observatory, there should be other instruments of less size and value appropriated to the use and instruction of academical students."

The erection of the observatory was commenced in 1822 and it was completed in 1824. However, when Airy was appointed Director, in 1828, very little had been done towards the fulfilment of this excellent programme. The only instruments were a couple of good clocks and a transit by Dollond; there were no assistants, and no observations had been published. The new Director at once entered upon his duties as defined in the above programme. He made observations with the transit instrument, and reduced and published them single handed. There seems to have been some difficulty about the assistants, and he accordingly induced the Senate in 1829 February, to revoke the former regulations and place the appointments in his hands, subject to the approval of the Vice-Chancellor. The first assistant, Mr. Baldrey, was appointed in 1829 June, at a salary of 80*l.* a year. At the same time, and apparently also at Airy's suggestion, the Senate appointed a Syndicate to visit the observatory once in each term, and to make an annual report to the Senate. The beneficial results of such an arrangement have been sufficiently recognised in its general adoption throughout the world.

The history of the observatory in these early years is worth studying in some detail as illustrating Airy's power of rapid organisation. He commenced residence at the Cambridge observatory on 1828 April 15, and was away from June 28 to September 17 on a scientific mission; and yet the volume

of observations for 1828 was published early in the following year, although "every part, from the making of the observations to the revising of the proof-sheets, was done by myself" (Camb. Obs. 1828: Preface). And it must be remembered that the best methods for making and reducing transit observations were then by no means clearly comprehended, even in what might be now regarded as essentials. A few extracts from the introductions to the first few volumes of Cambridge Observations will illustrate the early difficulties and the rapidity with which they were conquered better than any comments.

"In the management of the transit instrument it will be seen that I have adopted the laborious plan of applying numerical corrections for the errors of position, instead of relying on the mechanical removal of the errors. I believe that it is no more possible to keep the instrument exactly in position than to keep the clock exactly to sidereal time; and I have thought no trouble misplaced which gave greater accuracy to the results" (Camb. Obs. 1828).

"And I would warn future observers, who may wish to determine accurately the errors of their instruments, to place no confidence in catalogues, but to rely on the simple and independent methods which were used before even approximate catalogues were formed" (Ibid.).

"About this time I found, on examining the clock errors, that the transits of Polaris agreed in showing its assumed right ascension to be too great, by nearly $1^s{\cdot}2$" (Ibid.).

"The multiplication of the errors by the factors corresponding to the stars observed is always performed by means of a sliding rule" (Camb. Obs. 1829).

"The mural circle was mounted in 1832 October, and was divided by Mr. Simms upon its own pier in November of the same year. On 1833 January 5, the last essential parts were received, and on the next day observations were commenced. Mr. Glaisher, the assistant by whom the greater part of the circle observations had been made, arrived on the following day. The use of a mural circle was almost wholly new both to him and to myself: I believe, however, that very few of the observations are less satisfactory on this account" (Camb. Obs. 1833).

The last extract refers to a time when Airy had succeeded in getting the instrumental equipment of the observatory tolerably complete. A $3\frac{3}{4}$-inch equatoreal by Jones had been erected in 1832 June, and was used at once, principally for observations of *Jupiter's* fourth satellite, with the view of ascertaining *Jupiter's* mass. With the arrival of the mural circle the volumes of observations assume a form closely resembling that of the modern Greenwich volumes, so far as regards meridian work, occultations, and phenomena. The comparison is closer even as regards quantity than might be expected, for, during the year 1833, Mr. Baldrey observed about 5,000 transits and Mr. Glaisher about 5,000 zenith distances.

The mural circle, of course, brought new difficulties, notably the R—D discordance. Reflection observations of stars had been instituted by Pond at Greenwich about 1821, and the discordance had already been noticed, but not explained. Airy made a vigorous effort to trace it to its origin, but was fain to be content with an empirical formula; it must be admitted, however, that what escaped his sagacity has also eluded that of his successors to the present time.

Much information about this period may be gathered from the *Report on the Progress of Astronomy during the Present Century*, drawn up by Airy for the British Association at its second meeting in 1832. He "begs the indulgence of the Society since his own connection with astronomy is of short standing;" but it is difficult to imagine that the Report could have been more complete.

It is interesting to find how nearly simultaneous was the commencement of Airy's career with that of several institutions now familiar to us. We have already mentioned the foundation of the Cambridge Philosophical Society. The Royal Astronomical Society was founded in 1820; the *Astronomische Nachrichten* commenced in 1821; the Cape Observatory was planned by the Government in 1821 and finished in 1829; and the Parramatta Observatory in 1822. We read of the first transit circle being constructed for Bessel in 1820, and of Herschel's graphical method for reducing double stars in 1832, which Airy already recognises as "really a new step in science." On the other hand, there is much in the Report which sounds strangely in our ears. To a list of "all the public observatories with which he was acquainted," numbering 41, Airy appends the remark, "I am not aware that there is any public observatory in America, though there are some able observers," and the conclusion of the Report is mainly concerned with a serious complaint against English astronomers, on two grounds: "First, that in those parts of astronomy which depend principally on the assistance of Governments or powerful bodies, requiring only method and judgment, with very little science in the persons employed, we have done much; while in those which depend exclusively on individuals, we have done little. Secondly, that our principal progress has been made in the lowest parts of astronomy; while to the higher branches of the science we have not added anything."

For the grounds of this complaint we must refer to the Report itself; but one of them supporting the second charge is that "in England an observer conceives that he has done everything when he has made an observation; he thinks that anything beyond the very first stage of reduction ought to be left to others; . . . the reduction of Bradley's observations was left to a foreigner."

Airy certainly did his best to remove this national discredit, and the keenness with which he so early felt it must be remembered in studying his life. We have seen how actively he com-

menced the complete reduction of the observations at Cambridge; and it may be mentioned here that, besides his own observations, he afterwards reduced those of Groombridge, of Catton, and of Fallows; and we shall presently refer to the laborious reduction of the lunar and planetary results of Bradley, Bliss, Maskelyne, and Pond. Meanwhile, Airy had not neglected his more strictly professorial duties, nor his own scientific work. Immediately on his election as Plumian Professor he had instituted a series of lectures on practical astronomy at the observatory; and, although only a few minor scientific papers were written in the years 1827 to 1830, which we may presume to have been fully occupied with the organisation of observatory work, the following years produced a series of memoirs of first-rate importance in the establishment of the undulatory theory of light. Among the papers in the *Camb. Phil. Trans.* is one on the theory of circular object-glasses, which may be considered fundamental. The problem seems to have been evaded as too difficult by previous mathematicians. The case of a rectilinear aperture, or a rectilinear diaphragm covering an object-glass, had been worked out, "for though sometimes tedious it is never difficult." But in the theory of the circular object-glass a more difficult integral presents itself. Airy calculated this integral numerically for the first time. He never shirked an important piece of work of this kind. Some years later (1836–1838) he wrote a fine piece of mathematics on the intensity of light in the neighbourhood of a caustic, where he obtains expressions of great generality with admirable ease; but the importance of the paper lies chiefly in the numerical calculation which he undertook to complete it, and the manuscript of which fills a large volume, though the results are printed in a compendious table of a page. But this paper was written after he came to Greenwich, and we are now reviewing his Cambridge life. There are other papers on light in the *Philosophical Magazine*, including one on the achromatic centre of interference fringes, of great importance. But his most brilliant achievement was the memoir on the inequality of long period in the motions of the Earth and *Venus* (*Phil. Trans.* 1832), for which he obtained the Gold Medal of the Royal Astronomical Society in 1832. The work occupied him some years. The possibility of the existence of the inequality was first suggested to him by a study of the errors of Delambre's Solar Tables in 1827, when he had compared them with 1,200 Greenwich observations. The complete determination of the inequality required much labour, and we can well understand the tone of triumph in which the announcement of success was made to the Royal Society: "Thus terminates one of the most laborious investigations that has yet been made in the planetary theory. . . . I believe that the paper now presented to the Royal Society contains the first specific improvement in the solar tables made in this country since the establishment of the theory of gravitation."

In the year 1835 the Astronomer Royal (Pond) resigned, and Airy was appointed his successor. A correspondence with Airy on the subject had been opened more than a year before, but Pond's resignation was delayed by circumstances then unforeseen. Meanwhile Airy's scientific services had been recognised by a pension from the Government, and it appeared doubtful whether he had anything to gain, even pecuniarily, by vacating the position which he had made famous at Cambridge for the more arduous duties of Astronomer Royal. His gratitude to the Government for the above-mentioned mark of recognition determined, however, his acceptance of Lord Auckland's offer in June 1835, and he was finally appointed Astronomer Royal on June 22. He took possession of the Royal Observatory on October 1. He did not leave Cambridge without many natural regrets, and his leave-taking was protracted by several circumstances. During the last two years he had been busily engaged in erecting the Northumberland equatoreal, presented to the Observatory by the Duke of Northumberland. It was not without some misgivings that Airy accepted the offer of the telescope, which he regarded as a possible temptation to neglect the fundamental meridian work of the Observatory. But, having accepted it, he lost no time and spared no labour to secure the efficiency of the telescope. An unfortunate accident delayed the work by many months: the flint lens was chipped in or after grinding, and M. Cauchoix had to reduce the thickness a quarter of an inch to grind out the fault, and in consequence to alter the figures of all four surfaces. It was thus not till some time after his appointment at Greenwich that Airy was enabled to report the completion of the mounting of the telescope, which he had begun and considered it his duty to finish. Again, his departure was so sorely felt by the University that his successor and others begged him to give one more set of lectures in the following spring; and though this involved an absence of five weeks from Greenwich and much extra labour, he obtained the necessary permission from the Admiralty and gave the lectures.

From the time of his appointment at Greenwich much of his life and work might be represented by a formula. The simplicity and directness of his character, which had revealed themselves in his mathematics, in the clearness of his literary style, and in the completeness of his fulfilment of any undertaking, now became apparent in the method and regularity with which he administered a large Government establishment. His early years were occupied by the orderly arrangement of the observatory as it stood, apart from the introduction of instrumental changes. He immediately instituted an annual Report to the Board of Visitors, and it is comparatively easy to gain from these Reports a general idea of the history of the Observatory. He set about arranging, binding, and cataloguing the manuscripts, and completed this work in 1841. That it was no mean labour may be gathered from the fact that "a practice was sometimes followed in Mr. Pond's time of taking books which had been only partially filled

by Dr. Maskelyne and inserting in the blank leaves calculations of a different date, and sometimes on very different subjects." He had already induced the British Association to obtain from the Government a grant for the reduction of the Planetary and Lunar Observations of Bradley, Bliss, Maskelyne, and Pond from 1750 to 1830, and this, though it must be dismissed here in a few words, was an immense labour. Ten or twelve computers were employed for many years under his supervision, forming a staff quite distinct from that of the Observatory. The work well deserved the award of the gold medal of the Royal Astronomical Society, which Airy received in 1847 for the Planetary Reductions, and the testimonial (equivalent to the Gold Medal) in 1848 for the Lunar Reductions.

The arrangement of the library at Greenwich was one of his first cares. The importance he attached to it may well be described in his own words, in which the spirit of his Report on Astronomy in 1833 is again made manifest: "The natural tendency, in an office so much pressed with routine work, and with official business having no very close relation to science, is to be degraded into a mere bureau of clerks; and it is difficult even for the director to resist the contagion. The only antidote is to place in the power of all the means of acquaintance with the literature and the foreign systems of astronomy; to make the principal persons, at least, familiar with the speculations of ancient and the theories of modern times. It is only thus that the character of an astronomer can be made to predominate over that of a mere observer or mere calculator" (Report for 1836).

In 1838 he obtained sanction for the provision of a Muniment or Record Room, in which to preserve manuscripts. From the first he made it a rule to transact business and give instructions almost entirely in writing, and to preserve *all* manuscripts. The advantages of this system have often appeared most unexpectedly; but it must be confessed that the rapid accumulation of volumes is a great drawback to its continuous adoption.

He also greatly extended the current system of reduction and publication, for which he found his Cambridge experience valuable. In 1841 he was thus enabled to say: "Within the last few years we have advanced little, or perhaps nothing, in the extent of our observations; but we have advanced greatly in the extent of our reductions. In a word, we have made little or no progress in the character of observers, but we have advanced very much in the character of astronomers," for the full meaning of which we must again refer to the Report of 1833. Finally, he reorganised the internal arrangements with regard to the observing duties of the assistants; and his new code of regulations was so successful as to be copied elsewhere.

Order having thus been established, Airy turned his attention to the improvement of the instrumental equipment. The Observatory having been originally instituted for improvement of lunar tables, he first devised an instrument, the

altazimuth, for observing the Moon more readily in the first and last quarters, when meridian observations can only rarely be made. We find his first proposal in a special address to the Board of Visitors in 1843, and at a special meeting in November 1843 his detailed scheme was approved. The instrument was not completed till May 1847, but meanwhile the whole arrangements for observation and reduction had been completely planned, and forms for reduction printed in detail, ready for the entry of the first observation in 1847, May 16, which have not been essentially modified since. In 1847 Airy determined to substitute a transit circle for the separate meridian instruments previously in use, and soon afterwards, having dismounted the zenith tube as inefficient, the idea of a reflex zenith tube occurred to him. These instruments were constructed during the next three years, and are still in use. The quality of workmanship demanded in their construction, especially that of the transit circle, taxed the skill of the mechanicians to the utmost. The necessary accuracy in the form of the pivots was only obtained, after many attempts, by carefully rubbing down by hand all places where a delicate spirit-level showed an excrescence, and each of the pivots cost six weeks of such labour. The completion of these instruments Airy regarded as a definite change in the Observatory equipment greater than any since Bradley's time. The chronograph, constructed from designs prepared entirely by himself, was introduced in 1854. In 1855 a circular was addressed to the Board of Visitors suggesting an improvement in the equatoreals, and a $12\frac{3}{4}$-inch object-glass was obtained from Merz, of Munich, and mounted on a massive framework according to the English system. The advantages of this system for strength and steadiness Airy had already recognised in mounting the Northumberland equatoreal at Cambridge, the designs for which he closely followed in the present instance. The characteristic of all Airy's instruments is great strength and solidity, and the mounting of this equatoreal is to be used for a 28-inch refractor now being made to replace the $12\frac{3}{4}$-inch.

With the inauguration of the South-east equatoreal terminated the entire change from the old state of the Observatory. In his report for 1859 Airy remarks: "There is not now a single person employed or instrument used in the Observatory which was there in Mr. Pond's time, nor a single room in the Observatory which is used as it was used then. In every step of change, however, except this last, the ancient and traditional responsibilities of the Observatory have been most carefully considered; and in the last the substitution of a new instrument was so absolutely necessary, and the importance of tolerating no instrument except of a high class was so obvious, that no other course was open to us. I can only trust that while the use of the equatoreal within legitimate limits may enlarge the utility and the reputation of the Observatory, it may

never be permitted to interfere with that which has always been the staple and standard work here."

Meanwhile other changes had taken place in the Observatory. A single computer, engaged experimentally in 1840, was found so useful that a number were gradually added to the regular staff. But more important than this was the addition of a new department for magnetic and meteorological observations. This was suggested in 1836, but not completely carried out till 1840, when the Royal Society recommended to the Treasury the importance of making a series of observations at some place near London, in general correspondence with Captain J. Clark Ross's surveying expedition to the Antarctic Ocean, in conformity with the plan drawn up by Professor Gauss, of Göttingen, for the simultaneous observation of the movements of the magnetic needle at various selected stations in both hemispheres. At Airy's instigation Greenwich was selected as this station, and in 1841 the new department was practically complete. Although instituted for a temporary purpose, its advantages and importance were soon so manifest that it became a regular part of the establishment, and has so remained. Observations were first made every two hours by the assistants; but the system of registration by photography was introduced in 1848, and relieved the severe labour previously necessary. The results of the magnetic observations have been summarised in several memoirs in the *Philosophical Transactions*. It is curious that in two of these, read in 1863 and 1868, Airy definitely gives his opinion that there was no evidence of a ten or eleven year period in the magnetic elements, such as would be demanded by a relation between sunspots and terrestrial magnetism; and it was not until 1879 that this relation was firmly established from the very same records by Mr. Ellis.

Another new department was added by Airy to the Observatory near the end of his career, and may be described as the Physical Department. In 1873 he commenced a systematic study of the Sun's surface by means of daily photographs, taken with a Kew photoheliograph; and in the same year a spectroscope was devoted to the determination of stellar motions in the line of sight; and thus for the first time equatoreal work became a part of the regular routine at Greenwich. The equatoreals had previously been used only occasionally—for the observation of occultations, phenomena of *Jupiter's* satellites, eclipses, and comets. It is to be remarked that the new departure was still in strict conformity with the duties of the Astronomer Royal as specified in the Royal Warrant, by which he is directed "to apply himself with the most exact care and diligence to the rectifying the tables of the motions of the heavens and the places of the fixed stars. . . ."

It has been above remarked that after the establishment of order and system in the observatory, Airy's life as actual Superintendent of the observatory work was so regular and methodical

as to leave little for the chronicler to remark. But his great energy found vent in a variety of other directions. Some of the extraneous work he did was doubtless not of his own seeking; though on reviewing his life one cannot but feel that between Airy and work there was always a mutual attraction. With his memoir "On the Intensity of Light near a Caustic," written soon after his departure from Cambridge, his purely scientific career, if this term may be applied to the production of theoretical investigations, practically closed; excepting only his Bakerian lecture in 1840 on "A new Polarity in Light." But his attention was occupied by many matters of great practical importance. In 1844 he thus sums up the extraneous calls on his time and energy: "Official superintendence, as Chairman of Committee, of the restoration of the national standards (of which the immediate superintendence is intrusted to Mr. Baily and Professor Miller). Reduction of the Irish tidal observations. Printing the account of Mr. Maclear's verification and extension of La Caille's arc. Assisting the Registrar-General in regard to the Meteorological Report affixed to the weekly Sanatory Report. Aiding Mr. Struve in his proposed determination of the longitude of Pulkowa. Arranging an enterprise to determine the longitude of Valentia in Ireland, for the measure of an arc of parallel, and for the fixing of a nautical zero."

The standards of length and weight had been destroyed in the great fire at the Houses of Parliament in October 1834, and the history of their restoration is given in the "Account of the Construction of the New National Standard of Length, and of its Principal Copies," drawn up by Airy in the *Phil. Trans.*, 1857. The work included the preparation and comparison of a large number of copies of the standards for distribution to public bodies in England and to foreign Governments, thus securing the legal standards against future loss from any possible accident to the national standards. The reduction of the Irish tidal observations was a most laborious piece of work; but space forbids more than the briefest reference to many of the things Airy did. The determination of the longitude of Pulkowa may be taken as representative of a long series of longitude determinations, both by chronometers and by telegraph, which Airy superintended, including Valentia, Cambridge, Edinburgh, Glasgow, Brussels, and Paris. At the end of the same Report (for 1844) we read of the important advice given to the Canada Boundary Commission. "The most difficult part of the boundary was a straight line of nearly seventy miles in length to join two defined points. The country through which this line was to pass is described as surpassing in its difficulties the conception of any European. It consists of impervious forests, steep ravines, and dismal swamps. A survey for the line was impossible, and a tentative process would have broken the spirit of the best men. I therefore arranged a plan of operations founded on a determination of the absolute latitudes and the difference of longitudes of the two

extremities. The difference of longitudes was determined by the transfer of chronometers by the very circuitous route from one extremity to the other; and it was necessary to divide the whole arc into four parts, and to add a small part by measure and bearing. When this was finished the azimuths of the line for the two ends were computed, and marks were laid off for starting with the line from both ends. One party, after cutting more than forty-two miles through the woods, were agreeably surprised, on the brow of a hill, at seeing directly before them a gap in the woods on the next line of hill; it opened gradually, and proved to be the line of the opposite party. On continuing the lines till they passed abreast of each other, their distance was found to be 341 feet. To form an estimate of the magnitude of this error, it is to be observed that it implies an error of only a quarter of a second of time in the difference of longitudes, and that it is only one-third (or nearly so) of the error which would have been committed if the spheroidal form of the earth had been neglected."

Two of Airy's greatest practical achievements are not referred to in this list: his investigation of the disturbance of the compass in iron ships, and his work in settling the gauge of railways. The correction of the compass for the influence of the iron of a ship was not a new question. There was already in existence the "Barlow plate," professing to correct the compass, but Airy pointed out the deficiencies of this and the remedy. In fact, he undertook an entirely independent investigation of the question, which was becoming important in consequence of the introduction of large quantities of iron in the construction of ships. In the year 1838 the iron steamship "Rainbow" was placed by the General Steam Navigation Company at his disposal, and the results of the elaborate series of experiments then made are published in a paper read to the Royal Society in 1839, in which, discussing these experiments, he gave a complete solution of the problem, and drew up a set of rules showing how in a simple and practical manner the compass could be made and maintained sensibly correct. This subject brought him afterwards a considerable correspondence, and in the year 1855 he communicated a further paper to the Royal Society, in which he discussed the compass errors of a number of different ships as observed in various parts of the world. The system as originally proposed by him in 1838 has, with some small modifications, been adopted by all other countries.

The only tangible recognition of this work which he ever received was a present of a gold snuff-box from the General Steam Navigation Company, "for his discovery of an effective corrector of the influence of local attraction upon the compass in iron steamships."

The work on railway-gauges occupied a considerable time, as may be seen from the "Astronomer Royal's Journal" for 1845. A Commission was appointed to inquire into the subject, and

many visits were paid to London for the hearing of evidence of all kinds; and in January 1846 experiments were made during a series of trial-trips at very high speeds. The final report was in favour of the present standard gauge, and in the present year (1892) the last broad gauge of the Great Western Railway, which alone has ever used any but the standard gauge, will disappear. Airy's railway experiments also included an investigation of the vibration effects caused in the surrounding soil, for the determination of the limits within which trains must not approach an observatory.

Another eminently utilitarian achievement was the connection, in the year 1852, of the Observatory with the general telegraphic system of the country, and the immediate establishment of a system of hourly time signals which were automatically transmitted from a clock at the Observatory (kept adjusted to exact Greenwich time) to the then principal electric telegraph centre in London for daily distribution by telegraph to different parts of London, and throughout the country along the different railway lines for the regulation of railway and public clocks, including the daily dropping of a time-ball at Deal for giving time to shipping in the Downs. This system was the precursor of similar systems in other countries.

But it was not only in matters of practical importance such as these that his energies overflowed. Besides paying the most careful attention to current astronomical events, which yet fell outside the routine work at Greenwich (such as total solar eclipses, of which he personally observed that of 1842 at Turin, that of 1851 at Gottenburg in Norway, and that of 1860 at Hereña in Spain), he was chiefly responsible for the carrying out of two great scientific investigations—the determination of the Earth's density by pendulum experiments at the Harton Colliery in 1854, and the determination of the solar parallax by observations of the transit of *Venus* in 1874. Both these had been long contemplated. The Harton Colliery experiments were the successful issue of a third attempt after two failures. In 1826 Airy and Whewell had commenced operations in the Dolcoath mine, one of the deepest in Cornwall, where they were to observe the swinging of pendulums at the top and bottom of the mine for the comparison of the effects of gravity at these points. The accident which interrupted them is thus described: "We were raising the lower pendulum up the south shaft for the purpose of interchanging the two pendulums, when (from causes of which we are yet ignorant) the straw in which the pendulum-box was packed took fire, the lashings were burnt away, and the pendulum with some other apparatus fell to the bottom. This terminated our operations of 1826."

With three other observers the experiments were again attempted in 1828, but were suddenly stopped by the occurrence of a "fall" in the mine, and the consequent flooding of the lower station by the rise of the water. No further attempt was

made till 1854, when the introduction of chronographic registration had afforded new facilities for comparing clocks at the top and bottom of the mine. The account of the operations is given in the *Phil. Trans.* for 1856. It was found that the pendulum at the bottom of the mine would gain $2\frac{1}{4}$ seconds per day on that at the top; or, in other words, gravity was greater at the bottom of the mine than at the top by $\frac{1}{19\,\frac{1}{90}}$ part; and from a knowledge of the density of the stratum of the Earth's surface pierced by the mine it was concluded that the Earth's mean density was 6·6 times that of water.

It is now somewhat difficult to realise the intense anxiety with which astronomers looked forward to the pair of transits of *Venus* of the present century. It was hoped that the solar parallax would be determined with the greatest precision if only proper care were taken in the observations; for it was thought that the foreknowledge of the phenomena of the "black drop," which had been gained by a study of the observations made in 1761 and 1769, would be sufficient to enable observers to guard against this disturbing cause. Airy could certainly not be accused of delay in considering the necessary preparations and precautions. In 1857 he opened a discussion as to the best means of observing the transits of 1874 and 1882 by a paper read to the Royal Astronomical Society. In 1865 we find him already looking beyond the transit of 1874 to warn the Board of Visitors that "in reference to possible observations of the transit of *Venus* in 1882, it will be necessary in no long time to examine the coasts of the Great Southern Continent."

The British expeditions were arranged and equipped under his guidance, and his "Instructions to Observers" are a model of what such documents should be. There were to be five "Districts": Egypt, the Sandwich Islands, Rodriguez, Christchurch (New Zealand), and Kerguelen Island; and these were subdivided into several stations. The numerous observers were trained for many months, before starting for their destinations, at the Royal Observatory; and although Colonel Tupman undertook a great deal of the labour of supervision, the whole enterprise was a serious addition to the work of the Astronomer Royal. A model was constructed to show the phenomena of the transit, and the observers all practised diligently with it. That the results for the actual transit were not so satisfactory as had been hoped was in no way due to any want of care in organisation, but to the unforeseen influence of the illuminated atmosphere of *Venus*. But for this, the world would have been in no danger of forgetting that it was in great measure due to Airy's influence that the Government aided so lavishly what promised at one time to be the most important astronomical adventure of this century.

It has been remarked that Airy's purely scientific work practically terminated with his Cambridge career. His determination of the motion of the solar system in space from the average drift of 1,167 stars must be regarded rather in the light of a direct

deduction from the regular routine of observation at Greenwich than as an original investigation, although the method of procedure was sufficiently new to be still quoted as Airy's method. In 1870 we find him looking back with some regret on the change in his life and work involved in his appointment to the post of Astronomer Royal. "I have often felt," he remarks to the Board of Visitors, "the desire practically to refresh my acquaintance with what were once favourite subjects—Lunar Theory and Physical Optics. But I do not at present clearly see how I can enter upon them with that degree of freedom of thought which is necessary for success in abstruse investigations." His life had indeed been a busy and distracted one; it is hard to believe that it was not spent in the right way, for the setting of things in order, if not the work he loved best, was accepted so willingly as his life work that he was equally content in correcting solar tables, in organising a great expedition, or in labelling a number of boxes "empty." And yet he would often smilingly protest to his friends that he was intended for a life of quiet and contemplation—"he ought to have been a rural dean." It is possible that his work at Greenwich influenced him more than he himself suspected; for when the longing to resume his work of earlier days came upon him in 1870, it crystallised into the undertaking of a laborious research in lunar theory for which his failing powers ultimately proved inadequate. The fundamental conception of his numerical lunar theory was worthy of him; but the carrying out of this conception involved a close attention to a most intricate series of calculations which was not possible at the age of eighty. If it be sad to see a man die in the ripeness of his age, it is sad to read Airy's final confession that the completion of the task was beyond him; but it is the more clearly apparent that he toiled unremittingly until he could toil no more.

We have omitted to speak of many things which would be important in the lives of most men, but are trifles in that of a giant. Airy was a voluminous writer from the time when he was appointed Lucasian Professor onwards. His volume of *Mathematical Tracts*, published in early Cambridge days, and dealing with Lunar Theory, Figure of the Earth, Precession and Nutation, and Calculus of Variations, to which were added, in the second edition, Planetary Theory and the Undulatory Theory of Optics, was practically the first of Cambridge text-books in the modern sense. Other text-books were written later, notably one on Magnetism, on which he delivered a course of lectures at Cambridge in 1869. He then remarked that the novelty of the subject and the want of adequate text-books for students made lecturing difficult. Besides articles on Trigonometry and Figure of the Earth, Airy contributed a very valuable article on "Tides and Waves" to the *Encyclopædia Metropolitana*. In this he attacked Laplace's celebrated solution of the problem of the tidal oscillations of an ocean of uniform depth. This attack drew forth a defence from Sir

William Thomson, and (although Airy continued to adhere to his own view) it may be suspected that Airy's opinion would now command the assent of but few competent mathematicians. His treatment of the problems involved in the propagation of waves in rivers and estuaries, and of the other phenomena of wave motion, forms an important and original contribution to hydrodynamical science. This portion of the memoir led him on to an approximate treatment of the general tidal problem, presumably in substitution for the rejected Laplacian theory, in which the ocean is treated as consisting of a number of zonal canals. The conclusions attained are of some general interest, but are avowedly remote from the actuality on the Earth's surface. If Laplace's theory be accepted, the value of this part of the paper falls considerably. It is now generally considered that the most original and important portion of the whole is that which treats of waves; but the article on "Tides and Waves" has been for many years the leading compendium of tidal theory and practice, and, notwithstanding the advance of science since it was written, still retains much of its value.

His miscellaneous writings include essays on the locality in which Julius Cæsar first landed in Britain, and other archæological questions.

He was also an excellent public lecturer, and could expound in a charming way either the swinging of pendulums for determination of the mean density of the Earth or the manner in which the Sun's distance may be determined from transits of *Venus*; and his useful and well-known work, *Popular Lectures on Astronomy*, is the reproduction, from shorthand notes, of six lectures delivered at the Museum at Ipswich in 1848, when such lectures were almost unknown. The work is still held in much favour.

The list of Airy's honours and distinctions is a long one. He was several times President of the Royal Astronomical Society, twice received its Gold Medal, and once the equivalent of a Gold Medal. He was President of the Royal Society, and received a Copley and a Royal Medal. He was awarded the Lalande Medal of the French Academy, and was one of its eight Foreign Associates. He was made C.B. in 1871 and K.C.B. in 1872, July 30, and was shortly afterwards knighted by her Majesty the Queen at Osborne. In 1875 he received the Freedom of the City of London (which had never before been conferred for scientific distinction), "as a recognition of his indefatigable labours in Astronomy, and of his eminent services in the advancement of practical science, whereby he has so materially benefited the cause of commerce and civilisation." He was a D.C.L. of Oxford, an LL.D. of Cambridge and Edinburgh, and an Honorary Fellow of Trinity College, Cambridge. He was a Chevalier of the Order Pour le Mérite of Prussia, of the Legion of Honour of France, of the Polar Star of Sweden, of the Dannebrog of Denmark, of the Rose of Brazil, and was the recipient of many personal favours, not the least of which was a present from

the Emperor of Russia of a gold cigarette-box set with diamonds. His collection of medals and decorations numbers nearly thirty altogether.

He married, on March 30, 1830, Richarda, daughter of the Rev. Richard Smith, of Edensor, county Derby. Lady Airy died on August 13, 1875, a few days after the celebration of the bicentenary of the foundation of the Royal Observatory. There were nine children of the marriage. The first three, all born at Cambridge, died early; the others—three sons and three daughters—are all living. One daughter is the wife of Dr. Routh, of Cambridge; the other two are unmarried, and were the constant companions of their father in his old age, more especially after his retirement from the Royal Observatory. He resigned his appointment as Astronomer Royal on August 15, 1881, in his eightieth year, and forthwith retired to the White House, on Croom's Hill, just outside the wall surrounding Greenwich Park; and here for ten years he passed a tranquil existence, varied only by regular visits to his country house at Playford, which had been customary for many years. He had a great affection for the neighbourhood in which his early days were spent, and was in return regarded with great veneration by the country-side. Writing to a local paper after his death, the present head-master of the Colchester Grammar School laments that, owing to irregularity in keeping the school register, no record remains of Airy's presence there; "and the present school building and plant are long subsequent to his time, so that no 'G. B. A.,' carved in wood or brick, remains a silent witness to his early energy." Just before his death his thoughts reverted constantly to these early days, and he would recall incidents, such as seeing Wellington's country recruits coming to have their hair cut in Colchester Castle-yard, which remind us how nearly his life spanned the nineteenth century. At the age of ninety he was in perfect physical health, and not only welcomed a large party of friends at the White House, but publicly performed the ceremony of lighting with gas the parish clock of Greenwich for the first time. An accidental fall some months afterwards, in his house at Playford, prostrated him for some time. He returned to Greenwich; but there internal complications developed which necessitated a serious surgical operation, and though for a time he appeared to rally, his strength gradually ebbed away, and he died on Saturday afternoon, January 2, 1892. He was buried in the churchyard at Playford on Thursday, January 7, with his wife and close to his three children.

H. H. T.

Joseph Beck was born at Stamford Hill in June 1829. He finished his school training at York, and on leaving there he was apprenticed to the well-known optical firm of Troughton and Simms. At the conclusion of his apprenticeship he became a partner in the firm of Smith and Beck, opticians, which

subsequently became known as that of R. and J. Beck, of Holloway and Cornhill.

After his marriage, in 1856, he lived in Stoke Newington, in which district he resided till his death, and always took an active interest in local affairs. He was one of the livery of the Goldsmiths' Company, and in 1873 was elected Common Councillor for the Ward of Cornhill. He also filled many other important offices connected with the Corporation, and was universally respected, not only as a zealous public servant, but as a man of high character and honesty of purpose.

As one of the leading opticians in the City he was thoroughly acquainted with the scientific aspects of his business, in which he was actively engaged during most of his life. He died of pneumonia after a few days' illness on April 18, 1891.

Mr. Beck was a Fellow of the Royal Microscopical Society, and was elected a Fellow of this Society on February 8, 1861.

Henry Lord Boulton was born December 31, 1829. A considerable portion of his life was spent in South America, and for the last twenty years he held the delicate and responsible position of English Consul-General at Venezuela. He was also chief partner in the Venezuelan banking house of H. L. Boulton & Co., of Carácas, who collect and remit to London the monthly instalments for the service of the Venezuelan debt. His death removes a valuable consular officer, whose prestige in Venezuela and knowledge of the country marked him out as specially competent to assist in the settlement of the boundary dispute between that country and Great Britain. Mr. Boulton died November 26, 1891. He was elected a Fellow of this Society January 11, 1889.

Franz Friedrich Ernst Brünnow was born in Berlin on November 18, 1821, being the son of Johann Brünnow, a Privy Councillor of State. He attended the Friedrich-Wilhelm Gymnasium from 1829 to 1839, when he entered the Berlin University, attending the lectures of Dirksen, Lejeune-Dirichlet, Ohm, and Steiner in Mathematics, Encke in Astronomy, and Dove in Physics. In 1843 he received the degree of Ph.D., his doctorial thesis being entitled "De Attractione Moleculari." Under the direction of Encke, Brünnow took a zealous part in the astronomical work of the Berlin Observatory, of which his numerous papers in the *Astron. Nachrichten* give evidence. He thus became, early in life, one of the band of earnest astronomers that Encke had gathered round himself at Berlin, including such well-known names as those of Galle, Bremiker, and D'Arrest. It is stated of Brünnow that he was present in the Berlin Observatory when Neptune was first recognised as a planet, and that one of the first notifications of its discovery that reached England was from him.

In the spring of 1847 he removed to Bilk, near Düsseldorf,

on his appointment as Director of the observatory at that place. During his residence here he published his well-known memoir on De Vico's comet, for which he received the Gold Medal of the Amsterdam Academy. It was during this period also that the excellent *Lehrbuch der sphärischen Astronomie* was prepared; the first edition, containing a preface by Encke, was published in Berlin in 1851. This text-book eventually reached a fourth edition, and was translated into English by Main, the Radcliffe Observer at Oxford, in 1860 (this translation contains Part I. of the original work only), into English by Brünnow himself in 1865, and has also, it is stated, been translated into Russian, Italian, and Spanish. These facts speak for themselves as to the estimation in which the *Lehrbuch* was (and is still) held by astronomers. It has perhaps done more to establish the fame of Brünnow than any of his other works.

In 1851 Galle was appointed Director of the Breslau Observatory, and on his departure from Berlin Brünnow took his place at the observatory as first assistant, in which capacity he remained from November 1851 to 1854. It was during this time that he computed the tables of *Flora*, based on Encke's method of procedure as given in the *Berliner Jahrbuch* for 1857. In later years, 1859 and 1869 respectively, tables of *Victoria* and *Iris* followed, the tables of the last-named planet being published at the expense of the Royal Astronomical Society. His work on the theory of these minor planets showed Brünnow to be a calculator of a high order, imbued with the best methods of the modern German school, as was indeed to be expected from a pupil—and evidently a favourite pupil—of Encke.

But a more independent position was soon to be his. In 1854 Brünnow was offered the post of Director of the new observatory in process of erection at Ann Arbor, Michigan, which he accepted. Whilst here he published for a short time a periodical under the title *Astronomical Notices*; it first appeared in Ann Arbor, afterwards in Albany, N.Y., whither he went in 1860 as Associate Director of the observatory in that town. Brünnow returned to Ann Arbor in 1861, and devoted himself to the study of the physical and astronomical constants of the observatory and of the instruments in it. His work on the errors of the circles of the Ann Arbor meridian instrument is perhaps not to be surpassed for thoroughness by anything similar to be found in the whole range of astronomical literature. The investigation was published in the *Astronomical Notices*.

Brünnow's relations to Watson (afterwards his successor at Ann Arbor) were very intimate and cordial. For a long time Watson was the only member of his class, and Brünnow assiduously delivered lectures to that class. It is said that it was at that time a common sight to see the professor talking in an enthusiastic and excited manner to the attentive class of one. When asked why he devoted so much time to so small a class, Brünnow replied: "That class consists of Watson." This high

estimate of his pupil's ability was, as is well known, fully justified by Watson's subsequent career.

In 1863, after the outbreak of the war, Brünnow resigned his position at Ann Arbor, and in 1865, on the death of Sir W. Hamilton, was appointed Andrews Professor of Astronomy in the University of Dublin, and Royal Astronomer for Ireland.

The work of organising the Dunsink Observatory and of placing it on a modern footing fell to the lot of Brünnow, who proved himself thoroughly competent to carry out the needed reforms. Under his direction the South object-glass of $11\frac{3}{4}$ inches aperture was mounted so as to form an excellent equatoreal telescope, and with it he carried out his well-known researches on stellar parallax, which testify so highly to his skill and assiduity as an observer.

The first and second parts of *Astronomical Observations and Researches made at Dunsink* were published by Brünnow in 1870 and 1873 respectively, and contain the results of his work with the South refractor. They are models of what such publications ought to be, lucid in arrangement, clear in exposition, every part of the work given in sufficient detail to enable anyone, with but little trouble, to follow the various steps of the reductions. The stars to which he devoted particular attention were *α Lyræ*, *σ Draconis*, *Groombridge* 1830, 85 *Pegasi*, and *Bradley* 3077; and his work on these brought out clearly the high order of accuracy attainable by a skilled observer in observations of differences of declination with a micrometer. The third part of the above-mentioned publication contains some additional observations made by Brünnow during his tenure of office, which were edited and published by his successor, Sir R. Ball, the present Royal Astronomer for Ireland.

In 1874 Brünnow resigned his position in Dublin on account of failing health and eyesight. He retired first to Basle, then in 1880 he removed to Vevey, finally, in 1889, he took up his residence in Heidelberg.

After his departure from Dublin, the weak state of his eyes prevented Brünnow from engaging to any extent in scientific work, and thus he was enabled to give more time to music, of which he was very fond, and for which he possessed a remarkable talent. It is said that he once remarked, with quite too modest a view of his important contributions to astronomy, that he ought to have devoted himself entirely to music.

In March 1857 Brünnow married Rebecca Lloyd, daughter of Rev. Henry P. Tappan, at that time President of Ann Arbor University. Their only son, Rudolf Ernst, is now Professor of Oriental Languages at Heidelberg.

His death was quite unexpected. He had suffered for a long time from weakness of the heart, and was seriously ill in June of last year. He, however, partially recovered, and was making preparations for a journey into Switzerland when he was again taken ill, and died on August 20, 1891, in Heidelberg, at the age

of nearly seventy years. He was elected a Fellow of this Society May 14, 1869.

William Chimmo was born in the year 1828, and entered the Royal Navy in 1841, when only thirteen years old. He obtained the rank of lieutenant in 1850, and of commander in 1864. He served in the first and second China wars, against pirates in Borneo, and for six-and-a-half years was engaged in the *Herald* in the search for Sir John Franklin. Afterwards, as lieutenant of the *Iano*, he led the successful search for the lost expedition of Mr. Gregory and his party in Torres Straits, and assisted in the magnetic observations during the voyage of the *Royal Charter* to Australia. In command of the *Sea Gull* he was engaged in the survey of the west coast of Scotland, and as commander of the *Gannet* in the survey of Trinidad and the exploration of Labrador. He also explored the Sooloo Islands, where he had three officers and two men wounded in the attack upon a nest of pirates, of whom 190 were killed.

From 1856 to 1858 Captain Chimmo was secretary to the Hydrographer of the Admiralty. The greater portion of his life was devoted to the Hydrographic Survey, and he wrote several papers on the result of deep-sea soundings in the Atlantic, on which he was employed. His only communication to this Society was an account of the great shower of meteors on November 14, 1867, which he observed when surveying in the West Indies.

After his retirement from the Navy, with the rank of post-captain, in 1873, he settled at Weymouth, where he died, October 30, 1891, at the age of sixty-four. He was a Fellow of the Linnean, Royal Geographical, and Meteorological Societies. He was elected a Fellow of this Society on November 11, 1859.

Albert Escott was born in Somersetshire in 1840, his father being a member of an old county family. His father died in 1845, and in 1851 the son entered the Royal Hospital School, Greenwich, as pupil in the Upper School, which at that time consisted of the sons of naval officers. The first years of his school life were passed under the care of the late Rev. Dr. Hill, and afterwards under that of Mr. John Riddle. In 1855 Mr. Escott was appointed senior pupil teacher in the Upper School, and after three years became assistant master in the Nautical School, and was afterwards second master in Section C. He was appointed head master in 1870, at which time the school was entirely reorganised. In 1874 an important change was made, naval schoolmasters being sent to be trained by Mr. Escott and his assistant at Greenwich, from which certificates were granted, instead of at the training colleges to which naval schoolmasters had been formerly sent. After the death of his former teacher, Mr. John Riddle, Mr. Escott edited the 8th edition of that

author's well-known treatise on Navigation. Mr. Escott was a Freemason, and took an active interest in the charitable institutions connected with that body, besides filling various parochial and other public offices. He was a man of marked ability and varied attainments, and by his personal qualities he won the affection and esteem of a wide circle of friends.

Mr. Escott died October 28, 1891. He was elected a Fellow of this Society May 13, 1864.

Thomas Henry Hovenden was born in Finsbury, November 4, 1833. He was educated privately, and on leaving school was articled to a solicitor. He was afterwards for many years the senior member of the firm of Hovenden, Heath & Berridge, surveyors, of Bishopsgate Street, from which he retired on account of failing health a few years before his death. Mr. Hovenden was a member of the British Archæological Association, and was elected a Fellow of this Society, December 12, 1884.

John Merrifield was born August 24, 1834, at Petertavy, on the borders of Dartmoor. He received his early education at the Tavistock National School, and after passing two years at the Exeter Training College was appointed elementary schoolmaster at Marytavy. His spare time was devoted to surveying and chemistry, and he was much sought after as an analyst. His natural love for mathematics, however, led him in 1862 to leave Marytavy for Plymouth, to become the founder and head master of the Plymouth Navigation School, thenceforward occupying himself in astronomy and kindred subjects.

In 1860 he published, in conjunction with Mr. Evers, a *Treatise on Navigation and Nautical Astronomy*. In 1876 he published a work on *Magnetism and the Deviation of the Compass*, and in 1887 a *Treatise on Nautical Astronomy*, in which he introduced his own method of clearing the lunar distances. In 1888 he received the Bronze Medal of the Falmouth Polytechnic Exhibition for an artificial horizon for sea use.

Mr. Merrifield's interest in education was shown by the science classes conducted by him, in most cases for the love of teaching, in which students were instructed in the elements of mathematics. He was a Fellow of the Royal Meteorological Society, and made and tabulated regular observations for nearly twenty-seven years. At the time of his death he was engaged in preparing for publication a work on *Climate and Health*.

Mr. Merrifield died June 27, 1891, having been in failing health for nearly two years. He was elected a Fellow of this Society February 10, 1865.

Jesse Scoffin Nimkey was born in 1838. He was engaged in a business which demanded most of his time and attention, but

was an assiduous student of astronomy, especially during his later years. He had an observatory built for his 6-inch telescope, and employed his skill as an artist in making drawings of the Moon and planets. He constructed an ingenious model for illustrating and demonstrating the phenomena of the solar system, the longitude and right ascension of the Sun and Moon, right ascensions of stars, &c. The model was exhibited at the People's Palace in 1887.

Mr. Nimkey was a skilled musician, and was an organist in London for more than twenty-eight years. He died from a disorder brought on by over-work and study on December 17, 1891. He was elected a Fellow of this Society January 11, 1889.

Norman Robert Pogson was born on March 23, 1829, at Nottingham, where his father carried on an old-established business as a hosiery manufacturer. Being intended for a commercial career, young Pogson received only an ordinary education, but very early in life he evinced scientific tastes and a marked dislike of business. His desire for scientific information was encouraged by his mother, who procured him access for some time to the works of an optician and instrument maker at Nottingham. On the removal of his father to Manchester he succeeded in obtaining lessons in trigonometry and other branches of mathematics, and eventually Mr. Hind, sen., of Nottingham, suggested to his parents to send him to London, giving him a letter of introduction to his own son, Mr. J. R. Hind, at that time astronomer of Mr. Bishop's observatory in the Regent's Park. Here Mr. Pogson was enabled to study practical astronomy under excellent guidance, while he supported himself by giving lessons in mathematics. In 1847 he first introduced himself to the notice of the astronomical world by publishing parabolic elements of two comets, and in the following years he computed elements and ephemerides of various comets and minor planets. This led to his being engaged as an assistant at the Regent's Park Observatory, which post he only held for less than a year, as he was at the close of 1851 appointed assistant at the Radcliffe Observatory, Oxford. Here he was regularly employed in observations with the transit instrument from the beginning of 1852 to the end of 1858, but though he devoted himself with energy to the routine work required of him, he found time for other observations as well, and soon became distinguished in the two fields of work with which his name will always be associated—minor planets and variable stars. In 1852 he discovered the variability of *R. Cygni*, and in the course of years he found eighteen other variable stars, the last being *X. Capricorni*, found at Madras in 1865. In 1854 he picked up the planet *Amphitrite*, which had, however, been found by Mr. Marth the night before, but two years later he was more fortunate, when he discovered *Isis* (42), and, encouraged by this and by the Lalande Medal which it procured him, he found in 1857 two other planets, (43) and (46). In the mean-

time he had in 1854 been selected by the late Astronomer Royal as one of the observers in the pendulum experiments at Harton Colliery, near South Shields, for determining the mean density of the earth; but he continued to devote most of the time which he could spare from his official work to studies on variable stars and on the magnitudes of the minor planets. The number which he adopted as the ratio of light between each magnitude, 2·512, of which the logarithm is 0·4, became by degrees universally adopted.

By his discoveries and numerous contributions to the *Monthly Notices* and the *Astronomische Nachrichten*, Mr. Pogson had acquired considerable renown among astronomers, and when Dr. Lee, towards the end of 1858, wished to revive the activity of the Hartwell Observatory, the charge of which had become too onerous for himself and Admiral Smyth, owing to their advanced age, he felt that he could not do better than entrust his instruments to Mr. Pogson. A regular agreement was drawn up as to the future work of the observatory (which curious document may be read in the *Speculum Hartwellianum*), and on January 1, 1859, Mr. Pogson entered on his new duties. At Hartwell he continued his favourite studies, especially devoting his time to a great piece of work which he had already commenced at Oxford in 1853—viz., an atlas of variable stars. This gave for each telescopic variable a map of its vicinity, 80′ square (on a scale of three inches to a degree), containing all stars down to the twelfth magnitude, and giving the accurate magnitudes of a certain number of comparison stars. In February, 1860, he announced that nineteen of these maps were finished, and if he had remained at Hartwell or at some similar observatory, this valuable piece of work would doubtless long ago have been published. In October, 1860, he was, however, appointed Government Astronomer at Madras, in succession to Captain Jacob, and left England soon after.

When Mr. Pogson arrived at Madras in the beginning of 1861, the observatory had recently been provided with a transit-circle by Troughton and Simms, which had arrived just before Captain Jacob's departure. It was mounted and ready for work in the spring of 1862, when systematic observations were at once commenced by three native assistants. The objects selected for observation were the brighter stars down to the fifth magnitude, the Moon and Moon-culminating stars, *Mars*, and the brighter of the minor planets, but particularly all known variable stars, and as many stars as possible south of 120° N.P.D., down to the ninth magnitude. From 1862 to 1887 more than 50,000 observations of fixed stars were made, but it was not till the last-mentioned year that Mr. Pogson was able to overcome the difficulties which up to then had prevented him from publishing any of the results of the observations. He then commenced the publication of annual catalogues of individual results and mean positions for each star, but he only lived to give three

volumes to the public, embracing the years 1862 to 1870. In addition to the unpublished parts of this work there are still awaiting publication: a catalogue of 2,200 stars for 1855, from observations made from 1853 to 1858 under Captain Jacob and Major Worster, as well as a number of miscellaneous observations made before 1860; also all the observations of minor planets, comets, occultations, and light-comparisons of variable stars. The only astronomical publication issued from the Madras Observatory under the direction of Mr. Pogson, in addition to the three volumes already mentioned, is the account of the telegraphic determination of the difference of longitude between Madras and eight other stations.

The disappointment which Mr. Pogson must have felt at having to wait for so many years before being enabled to publish his meridian work was not the hardest one which he had to bear. When he first commenced work at Madras he expected that a European and scientifically-trained first assistant would very soon be appointed, and he had planned a continuation of Argelander's *Durchmusterung* in the southern hemisphere, and the subsequent observation on the meridian of the stars thus mapped. All these hopes he was destined to see dashed to the ground within a few years of his arrival in India. But this did not prevent him from continuing his former work, and he went on searching for minor planets, of which he at Madras found five and re-discovered the lost *Freia*. The name which Pogson had acquired as a skilful observer caused Klinkerfues in 1872 to address his well-known suggestion to look for the lost comet of *Biela*, near *θ Centauri*, to the astronomer at Madras, who readily acted on the suggestion and found a small comet not far from the spot indicated. But his favourites, the variable stars, were not forgotten; he added seven new ones to those already known, and continued to work on his Atlas of variable stars during the years of his residence in India. The difficulties connected with the observations required for this work, which could only be carried on during the absence of the Moon, have unfortunately prevented this Atlas from being completed; and here again we cannot help regretting that Mr. Pogson was drawn away from the class of work to which he felt specially inclined, and left to struggle without proper assistance against an overwhelming amount of routine work, including magnetic and meteorological observations, with plenty of arrears to be worked up.

Mr. Pogson was created a Companion of the Indian Empire on January 1, 1878.

During the thirty years which Mr. Pogson spent in India he never took any holidays. Even when very far from well, about six months before he died, he was indefatigably active in dismounting and cleaning three of the principal instruments, and in May last, though seriously ill, he had a look at *Mercury* on the Sun's disc with an old $3\frac{1}{2}$-inch refractor from Hartwell. He

died on June 23, 1891, leaving a large family by his first marriage, and a widow and two young children. He was elected a Fellow of this Society on May 11, 1860. J. L. E. D.

Henry Pratt was born in Brighton on March 29, 1838, and was the eldest son of Mr. Henry Pratt, a naturalist and taxidermist of the same town. The son was almost entirely self-educated, but owed much to two years' instruction under Mr. Strugnell, of Christ Church School, Brighton, who helped to inculcate the love of study and to form the orderly habits of thought which Mr. Pratt showed in after years. By profession he was a watchmaker, and was esteemed for his ingenuity in works of mechanism and the skill which he could command in delicate workmanship. Astronomy, however, was his favourite pursuit, though all his studies in this direction had to be conducted at the close of a hard day's work in his business.

The instrument which he employed was a With-Browning reflector, with an excellent mirror of 8·15 inches aperture. He had a keen sight, and was a skilled draughtsman. These advantages, combined with indefatigable industry, enabled him to do much useful work, and he soon became known as an astronomer far beyond the limits of his native town.

During the partial solar eclipse of 1873 May 27, he was fortunate in obtaining observations of a portion of the Moon's limb beyond the disc of the Sun. In his first contribution to the *Monthly Notices* (vol. xxxiii. p. 577) he gave an account of his observation of this interesting phenomenon; the Moon's limb was seen to a distance of about 5 minutes of arc beyond the Sun's disc, of course projected upon the solar corona. The instruments were repeatedly changed, and it appears certain that the phenomena observed were not of instrumental origin.

Mr. Pratt was an assiduous observer of the lunar surface, and especially of the delicate markings and minute craterlets upon the floor of *Plato*, which he carefully studied. In 1877 he communicated to the Society some short but suggestive notes on *Mars*, accompanied by drawings which are preserved in the library. In 1880 he published a careful determination of the rotation period of *Jupiter*, which involved the observation of 321 rotations of the planet, and he showed reason for considering that the generally accepted rotation period was somewhat too short. In vol. xliv. of the *Monthly Notices* he gave the results of a series of observations of *Saturn*, accompanied by a fine drawing of the planet, and he appears to have obtained satisfactory observations of the innermost satellites, and of the fine division of the rings. In the same volume he published his observations of the *Merope* nebula in the *Pleiades*, which he was well able to see with his reflector, using a low-power Kellner eyepiece; with a slotted diaphragm to conceal the bright stars he even succeeded in seeing the faint patch of nebulosity

between *Merope* and *Alcyone*, first detected by Dr. Common with the 36-inch reflector.

Mr. Pratt was also a contributor to the *Astronomical Register* and other journals, and supplied regular weather reports to a local newspaper.

In August, 1890, his health having broken down, he decided, on the recommendation of his medical adviser, to leave Brighton and settle at Crowborough, Sussex. This intention he was never able to carry out, as his strength gradually failed, and on March 7, 1891, he died at Brighton, in the fifty-third year of his age.

He was elected a Fellow of this Society on April 12, 1872.

Edward Williams Snell was born at Maker, Cornwall, in the year 1834. At the age of eighteen he went to Dr. Burney's School at Gosport, where he prepared pupils for the Army and Navy; and in 1859 he became mathematical master at the Royal Hospital School, Greenwich, from which post he retired in 1870. For the last eighteen years of his life he was conductor of a private school at Blackheath, where, owing to his untiring energy and the help he was always ready to give his pupils, he was particularly successful in preparing them for examinations, and gained their lasting affection. Mr. Snell had only just retired from work when he was attacked by a painful illness, which caused his death July 7, 1891, at the age of fifty-seven. He was elected a Fellow of this Society March 10, 1871.

Eduard Schönfeld* was born at Hildburghausen, in the Duchy of Meiningen, on December 22, 1828. His mother taught him to read, and he appears to have taught himself the rudiments of arithmetic. Later on, when he went to the Gymnasium of his native town, he could give assistance to the pupils of the highest classes in mathematics. Following the usual curriculum of the school, he remained two years in the senior class before attaining the legal age for the final examination. On leaving the Gymnasium, young Schönfeld expressed his desire to study astronomy, but abandoned the idea at the time, at the wish of his father, who considered it a profession without prospects, and, by the advice of his uncle, he studied architecture, first at the Polytechnical School at Hanover, and then at Cassel.

In the spring of 1849 he worked in the chemical laboratory at Marburg under Bunsen, but his former love for astronomy was revived by Gerling's lectures, and, making it his sole study, he translated the first book of the *Mécanique Céleste* and the *Theoria Motus* during his residence at Marburg. His first astronomical observation was an occultation of γ *Arietis*, made on November 29, 1849. In 1851 Schönfeld availed himself of an opportunity to visit the Bonn Observatory, and the charm of

* Abridged from an article by Prof. Krueger in *Vierteljahrsschrift*, Jahrgang xxvi., Heft. 3.

Argelander's personality was so great that on his return to Marburg he wrote to him of his great desire to study at Bonn. Argelander received the proposition most warmly, and at Easter, 1852, Schönfeld matriculated at Bonn, and attended Argelander's lectures. He also observed diligently, and took part in reductions of observations of newly-discovered planets and comets. Argelander had such confidence in Schönfeld's ability that he appointed him to a vacant assistantship, though he had not yet taken his degree. In the following year, 1854, Schönfeld won his doctorate with distinction by his treatise *Nova Elementa Thetidis*.

We now come to an important event in Schönfeld's life—viz., his connection with the Bonn Survey of the Northern Heavens, in the successful completion of which he had so great a share, even after he had left the Bonn Observatory. In the accuracy of his observations and scrutiny of the results he vied with his great master, and he never lost courage, even when the strain of observing throughout the night and reducing the results in the day became almost too severe. After the Bonn Survey Schönfeld turned his attention to the light-changes in variable stars, a problem that was at that time exciting the interest of astronomers, owing to the discovery of new stars and the observations of Argelander. Schönfeld availed himself of Argelander's simple and trustworthy methods, and the evenings which could not be utilised for zone work, on account of moonlight, were employed in making as complete observations as possible of the minima of *Algol* and *S Cancri*. Schönfeld now became a Privat-Docent in the University, but did not long exercise this function, for in 1859 he was appointed Director of the Mannheim Observatory, through the influence of Eigenlohr, who applied to his friend Argelander for advice. The Mannheim Observatory must have seemed antiquated when compared with the convenient and perfectly-arranged observatory at Bonn. From its position and construction it was almost impossible to mount satisfactorily even a single instrument that would be capable of good work, and Schönfeld had to be contented with a small parallactic refractor of Steinheil's of 73 lines aperture. His chief work with this instrument was on nebulæ and variable stars; he also observed comets and new planets with regularity. With regard to nebular work, Schönfeld chose the objects to be observed, with few exceptions, from Herschel's Catalogue, on the ground that these could be sufficiently well observed with his refractor. He connected the nebulæ with the neighbouring stars by successive ringmicrometer determinations. Four hundred and eighty-nine observations of nebulæ by Schönfeld are collected in two volumes of the publications of the Mannheim Observatory, published in 1862 and 1875 respectively. His researches on variable stars are published in two catalogues in the *Jahresberichte* of the Mannheim Physical Society, Nos. 32 and 39, dated respectively 1866 and 1875. The first catalogue

comprised 119 stars, the second 143, for which the variability had been ascertained.

Schönfeld was a member of the Astronomische Gesellschaft from its foundation in 1863, and from 1863 to 1869 was a member of the Council, but without any special office. In 1875, in conjunction with Winnecke, he undertook the duties of Secretary of the Society and Editor of its publications, and also the preparation of the ephemerides of variable stars.

On the death of his master and life-long friend, Argelander, which occurred on February 17, 1875, Schönfeld was appointed Director of the Bonn Observatory and Professor in the University.

Shortly after entering on his new office he began preparations for an extensive work—the greatest and last of his life—i.e., the extension of the Survey of the Heavens to 23° South Declination. The experience gained in the Northern Survey gave opportunity for the introduction of newer and more convenient methods. Schönfeld determined to use a more powerful telescope—one of Schröder's refractors of 70 lines aperture. The use of a higher magnifying power necessitated a smaller field of view, and consequently narrower zones and a greater number of them; but the gain in accuracy of position was important, as well as the diminution of the danger of omitting stars in a rich field. Schönfeld himself superintended both observations and revision. From 1875 to 1881 610 zones were observed, and by February, 1884, 16 zones more were added, which, with the preceding zones, comprised 700 hours in Right Ascension. These observations furnished 363,932 single-star places as basis of a catalogue of 133,659 stars, which is published in vol. viii. of the *Bonn Observations*.

It is perhaps to be regretted that the Northern Survey had not been carried out in the same manner—i.e., with smaller zones and a more powerful telescope, an illuminated field, and, as far as possible, the same observer. But it was scarcely to be expected that one and the same observer should persevere through long years at the same work. All praise is due to Schönfeld, who attempted this survey, and carried it out in its smallest details. He was an extremely hard worker. It often happened during long periods that he remained almost uninterruptedly at his work from nine in the morning till three at night. Yet to him his work never seemed to progress fast enough. The 8th volume of the *Bonn Observations* appeared in 1886—in spite of the most strenuous exertions he could not publish it sooner.

His strong sense of duty and his learning, as profound as that of the greatest astronomer of our time, procured for Schönfeld a pre-eminent position among his colleagues at the University, and his benevolent and unassuming character gained him many friends. Through the Astronomische Gesellschaft he was brought into friendly relations with both old and young colleagues in his profession. He took part in the twenty-fifth

anniversary of the Pulkowa Observatory, and seized the opportunity of making the acquaintance of the astronomers there. In 1887 he attended the first Paris Congress for the photographic chart of the Heavens, and took part in the discussions. In 1889 he again went to Pulkowa, on behalf of the Prussian Minister of Education, to convey the congratulations of the German astronomers on the occasion of its Jubilee. Schönfeld was not permitted by his doctor to attend the meeting of the Gesellschaft, held at Brussels in the same year. To this meeting was sent to him from America the Watson Medal—a mark of esteem that he valued most highly. In 1891 it became apparent that Schönfeld was seriously ill, and on May 1 he died, after protracted suffering. He was elected a Foreign Associate of this Society November 8, 1878.

Proceedings of Observatories.

The following reports of the proceedings of observatories during the past year have been received from the Directors of the several observatories, who are alone responsible for the same :—

Royal Observatory, Greenwich.

The number of meridian observations made during the year 1891 was not so large as usual, owing to the fact that the transit-circle was under repair by Messrs. Troughton and Simms from August 10 to October 7, during which time the object-glass was repolished, and the micrometer screws and wire system of the eye end were renewed. The total number of transits observed was 4,731, and of zenith distances 4,433; and there will be 1,813 stars in the annual catalogue. The observations of clock stars and close circumpolars made during the years 1887–1891 are to be collected in a Five-year Catalogue of fundamental stars, which will give more recent determinations, for use in the *Nautical Almanac* and in the reduction of the Greenwich observations, than the general catalogues necessarily published at longer intervals.

The results of the preliminary observations for determining the dependence of personal equation on stellar magnitude were communicated to the Society in June last.

The mean error in R.A. of Hansen's Lunar Tables, with Newcomb's corrections, as deduced from eighty-four observations with the transit-circle in 1891, is $+0^{s}\cdot079$, a larger quantity than any for previous years since 1883. If we allow for the absence of observations in August and September, when the error has in previous years been greater than the mean, we must further increase this quantity.

Only one observation of horizontal flexure of the transit-circle was made in 1891, on May 4, the result being $+0''\cdot06$. The apparent correction to nadir observation, deduced from reflexion observations of north and south stars, is $+0''\cdot071$.

The results of the observations of thermometers, placed at different points of the transit-circle room, for the years 1888–1891, have been communicated to the Society. It appears that the distribution of temperature may affect the R—D correction,

and future experiments will be arranged more directly with the object of elucidating this point.

With the altazimuth the Moon has been regularly observed in the first and last quarters as before. On the occasion of the solar eclipse of June 6, Mr. Crommelin made an altazimuth observation of the Moon's dark limb. The instrument was also occasionally used for time determinations when the transit-circle was under repair.

Comet *b* 1891 (Wolf) has been observed with the Sheepshanks equatoreal on seven nights.

Five disappearances and six reappearances of stars occulted by the Moon have been observed, and forty-two phenomena of *Jupiter's* satellites. The observations of the solar eclipse on June 6 have been communicated to the Society.

Preparations were made for observing the transit of *Mercury* on May 10, and occultations of stars on the occasion of the lunar eclipse of November 15, but bad weather prevented any results being obtained.

The work with the 13-inch photographic telescope during the past year has been chiefly preliminary and experimental, several important questions having to be settled before the regular work of the photographic chart could be advantageously commenced. In all 204 photographs have been obtained during the year, the total number of exposures being about 830. These have been taken mainly with a view to determining the relation between diameter of image, duration of exposure, and brightness of star, and the results of this investigation have been recently communicated to the Society.

Besides this a considerable time has been spent in examining the effect of placing various screens before the object-glass, an investigation rendered necessary by a resolution of the Permanent Committee at their last meeting. Forty-five plates, containing 108 exposures, were taken with screens. Numerous photographs of trails of stars have also been taken to test the orientation, and from a discussion of these it appears that the line of collimation of the telescope is sensibly inclined to the polar axis at an angle of about 30′, the orientation for 65° N. Dec. differing by about 20′ from that for the equator. It has been found that the *réseaux* originally supplied decompose somewhat rapidly, and those which have been in use eighteen months are now seriously defective. A new *réseau* has been obtained from M. Gautier recently.

As regards the selection of guiding stars for the photographic chart, the catalogue of places (epoch 1900·0) for the Greenwich zones +65° to +80° is complete, the reductions for zones +80° to the pole being deferred. The catalogue for zones +60° to +62° of the 60°−65° zone to be photographed at Rome has been sent to Father Denza, and the rest is nearly finished. The first twelve hours of R.A. of the Oxford zones +25° to +29° have been sent to Oxford, and the other half

is nearly complete. A considerable amount of work has been done on the San Fernando zones ($-3°$ to $-5°$). The stars have all been selected for this zone, and the places for epoch 1900 have been computed for those between R.A. 12^h and 18^h.

The $12\frac{3}{4}$-inch telescope of the S.E. equatoreal was dismounted last November in preparation for the mounting of the new 28-inch object-glass, on which Sir H. Grubb is now engaged. The new 36-foot dome, to house the large telescope, described in the *Monthly Notices* for last May, is in course of construction by Messrs. T. Cooke & Sons, but the work has not advanced as rapidly as was hoped, and the dome is not yet ready for erection.

The regular series of observations of the displacement of lines in stellar spectra for the determination of their motion in the line of sight has not been continued during the past year, but as a preliminary discussion of the results obtained in former years appeared to show that they were affected to some extent by the position of the spectroscope, *Vega* and *Altair* were observed during the summer and autumn at as wide a range of hour-angle as possible, and with the spectroscope set to each of the four positions 0°, 90°, 180°, and 270°; the slit being parallel to the declination circle at 0°. The numbers of observations obtained of *Vega* are: at 0°, 39; at 90°, 42; at 180°, 36; and at 270°, 39; and of *Altair*: at 0°, 30; at 90°, 32; at 180°, 26; and at 270°, 29. The measures are now under discussion, but give clear indications of the existence of the systematic error referred to. The dismounting of the $12\frac{3}{4}$-inch equatoreal in order to prepare for the mounting of the new 28-inch telescope in its place was commenced on November 19, and further observations with the spectroscope were necessarily discontinued.

Photographs of the Sun have been taken with the Dallmeyer 4-inch photoheliograph on 224 days, and of these 525 have been selected for preservation, including sixteen photographs with a double image of the Sun, taken to determine the position of the wires with reference to the parallel of declination. Owing to the interference of the new Museum building in the south ground the Dallmeyer photoheliograph was removed on September 9 from its old position in the wooden dome south of the Photographic Offices, and was erected temporarily on the first floor of the new Museum. From this position it is possible to photograph the Sun for about two hours each day, except during the height of summer. A 9-inch photographic telescope by Grubb, presented to the observatory by Sir Henry Thompson, has been mounted on the Lassell equatoreal for use as a photoheliograph, and has been fitted with an enlarging camera to give 8-inch pictures of the Sun, and with a specially contrived exposing slit, made of aluminium, with which a very rapid exposure can be given. Photographs of the Sun have been taken with the Thompson photoheliograph on fifteen days, from November 10 to the end of the year. Photographs have also been received from India and Mauritius up to 1891 November 30; leaving

fourteen days in the year ending on that date for which no photograph is yet available for measurement.

The revival in the solar activity has been exceedingly marked during 1891. Whilst in 1890 there were no fewer than 173 days without spots, there were only 21 in 1891, and these all occurred during the first three months of the year; there have been no days without spots in 1891 since March 29. Many of the spot-groups have been very large and complicated, the one which first appeared on August 28 being especially noteworthy as the largest since June 1885.

Arrangements have been made with Professor McLeod, of the McGill College Observatory, Montreal, to determine the longitude of Montreal from Greenwich, and at the same time those of the cable termini, Canso in Nova Scotia, and Waterville, county Kerry. It was originally intended to commence the work in August 1891, but it was found impossible to get the requisite transit instruments, apparatus, and other preparations for four stations completed in time, and the commencement has been deferred till April 1892. It is proposed to divide the operations into two parts, separated by an interval of some two or three months in the summer, to detect or eliminate any possible systematic error depending on the season of the year. In the interval it has been arranged with the French Service Géographique to re-determine the longitude of Paris, as mentioned in the last report. For use in these and other longitude operations a permanent transit pavilion has been erected in place of the wooden hut set up in 1888. This building has been specially designed in the Department of the Director of Works to the Admiralty, with a roof consisting of a pair of semi-domes sliding apart so as to give a clear opening of 2 feet 6 inches, and avoid abnormal refraction by its circular form.

To provide additional accommodation for chronometers, a south wing to the new octagonal Museum is to be built in the present year, this wing forming part of a larger scheme for a cruciform building to accommodate the physical branch of the Observatory. A proposal is under the consideration of the Admiralty for an electric-light installation, the gas-engine, dynamo, and storage batteries being placed at the south end of the observatory enclosure, as far as practicable from the magnetic observatory.

The volume of Greenwich Observations for 1889 was passed for press in August last, and has been distributed. The volume for 1890 is well advanced.

The Treasury having authorised the addition of two assistants to the staff, Mr. Crommelin was appointed last May as the additional second-class assistant, and Mr. Lewis has been promoted to be the additional first-class assistant. It may also be mentioned that Mr. Downing has been appointed Superintendent of the *Nautical Almanac*, Mr. Thackeray being promoted to the vacancy in the first-class thus occasioned. There are thus

vacancies for two second-class assistants, which have been filled up quite recently by the appointment of Mr. W. W. Bryant and Mr. T. C. Hudson.

Royal Observatory, Edinburgh.

During the past year Mr. Thomas Heath has continued to make out the weather returns for the Registrar-General for Scotland, besides distributing the time and taking the meteorological readings. Mr. Heath has also made preparations for comparing the individual star-places of the Edinburgh observations with the Fundamental Catalogue of the *Astronomische Gesellschaft*. Already the 519 stars of Auwers' Catalogue which occur in the Edinburgh volumes have been reduced, with the proper motions of the *Astronomische Gesellschaft* Catalogue, to the years in which observations have been made. Within the year Nos. 13 to 21 of the Edinburgh Circulars have been distributed. For various detailed ephemerides of comets observers are again indebted to Herr A. Berberich, of the Berlin Rechen-institut.

The site of the new observatory has been enclosed by a light wire fence, the buildings staked out, and the foundations partly cleared. The pipes for water-supply and drainage are being laid and a pumping-chamber is also in progress. The final specifications of the observatories and dwellings are now drawn out and printed. It is expected that invitations for tenders will appear within a few days.

At Dunecht the packing of a number of the smaller instruments, and, later on, of the more delicate parts of the transit-circle, has been personally superintended by Dr. L. Becker.

Early in the year Dr. Becker undertook the reduction of the meridian observations of nebulæ mentioned in former reports. Advantage was taken of visits to Dunecht in March and May to supplement the work already done by 172 further observations. The whole of the materials were afterwards combined and compared with the results obtained by previous workers in the same field. Details of this investigation, together with a catalogue of the places of 217 nebulæ, will shortly be printed.

A paper, also by Dr. Becker, on the latitude of Dunecht as found by transits in the prime vertical, is also ready for the press.

The Makdougall-Brisbane prize of the Royal Society of Edinburgh has been awarded to Dr. Becker for his paper on "The Solar Spectrum at medium and low altitudes," of which some account was given in last year's Report.

In July Professor Copeland communicated a paper, "On the bright streaks on the Moon," to the Royal Society of Edinburgh, which will appear in their Transactions. It was illustrated by a model of the Moon, the streaks on which are produced by a coating of minute glass spherules, these having the property of

throwing back the light when illuminated from the front, while under other conditions they are scarcely visible. The remarkable property possessed by the lunar streaks of becoming conspicuously visible only near full Moon is thus shown by the streaks on the model. Photometric measures of the model under various illuminations yielded a phase-curve analogous to that derived by Zöllner from his own and Sir J. Herschel's observations of the brightness of the Moon.

Royal Observatory, Cape of Good Hope.

Observations with the transit-circle have been continued regularly throughout the year 1891. The principal objects of observation have been the Sun, *Mercury*, *Venus*, stars for a Ten-year Catalogue for 1890, stars occulted by the Moon, stars employed for latitude determinations in the Geodetic Survey of South Africa, comet comparison stars, and stars employed in zones for determining the scale value of the heliometer.

The work accomplished with the transit-circle in 1891 has been as follows:—

	R.A.	N.P.D.
No. of observations of ⊙ (both limbs)...	92	92
„ „ Mercury...	40	40
„ „ Venus	76	76
„ „ Azimuth stars	534	...
„ „ Catalogue stars	5470	6776
„ „ Stars for personal equation ...	336	...
Total	6548	6984

in addition to

509	determinations	of	Run.
50	„	„	Flexure.
110	„	„	Collimation.
514	„	„	Level.
509	„	„	Nadir.

The weather has been very unfavourable for observing during the latter half of the year; the heavy "South-Easters," with the unsatisfactory conditions of definition accompanying them, set in at a much earlier date than usual. Thus, during the last four months of the year, there were only twenty-five nights on which really satisfactory observations could be made.

The Zenith Telescope.—Since the completion of the first series of observations (mentioned in last year's report) the zenith telescope has been dismounted and thoroughly overhauled. The definition has been greatly improved by a new prism; two levels have been introduced, instead of one, for measuring the change

in the zenith distance of the optical axis in the two positions of the instrument. A self-registering micrometer has also been added, and several mechanical defects remedied. The efficiency of the instrument seems to be greatly enhanced by these improvements, which have been carried out by Messrs. Repsold. From 1892 February 1, the instrument will be devoted to a determination of the Constant of Aberration by methods independent of variation of the latitude, but including its determination.

The occultations during the total eclipse of the Moon on November 15, which were predicted for many observatories by Dr. Döllen, were observed at his request as follows:—

Observer.	Instrument.	No. of Phenomena.
Gill	10-inch guiding telescope of the photographic equatoreal	12
Finlay	7-inch Merz	8
Pett	6-inch Grubb	4
Cox	7-inch Heliometer	5

Full particulars have been communicated to the Society. This observatory is at great disadvantage in the observation of such phenomena, owing to the want of a larger telescope.

In addition to the above, the following occultations were observed during the year:—

Disappearances at the dark limb	17
Reappearances „ „	7
Reappearances at the bright limb	1
	25

The reappearance at the bright limb was that of σ *Sagittarii* on November 6. Some of these phenomena were observed by two or more observers. The figures given are the number of phenomena successfully observed, not the number of observations by different observers.

Only a very limited number of comet observations have been made, viz.:—

Comet Barnard-Denning...	3 nights.
Comet 1891 *e*	1 night.

With the heliometer, 219 measures of the mutual distances of *Jupiter's* satellites, and the same number of position-angles have been made in response to Dr. Elkin's request for co-operation with Yale, for a determination of the mass of *Jupiter*, and the correction of the orbits of the satellites. Observations have been made on forty-one nights for the parallax of β *Orionis*, ϵ *Orionis*, α *Eridani*, β *Crucis*, α *Piscis Australis*, τ *Ceti*, and α *Crucis*. The exceptionally bad definition during the last four

months has greatly limited the output of refined heliometer work—indeed, for three successive weeks of nearly clear sky it was impossible to make a single satisfactory observation of *Jupiter's* satellites, so agitated and *woolly* were the images.

H.M. Astronomer went to Europe in February for the purpose of attending the *réunion* of the Permanent Committee of the Astrophotographic Congress at Paris. Advantage of this opportunity was taken to return the object-glass of the photographic telescope to Sir Howard Grubb for correction of the optical imperfection mentioned in the last report. Sir Howard Grubb found a serious error in the figure of the outer surface of the crown lens, which he is certain did not exist at the time he applied his previous final tests. The defective surface has been reground and refigured, and, thanks to the kindness of Professor Pritchard, the object-glass was tested at Oxford, under his supervision, by Mr. Plummer. The instrument now gives good photographic images.

Some delay has been caused in the prosecution of the chart work by the non-arrival of photographic plates; they have now (January 12) just come to hand.

The work done with the photographic telescope has been:—

Iris comparison stars	21	exposures.
Victoria comparison stars	75	„
Focussing and testing	112	„
Screen experiments...	16	„
Jupiter	270	„

The *Jupiter* exposures extended over forty-four nights, and were made for the purpose of determining the relative co-ordinates of the satellites in connection with the work undertaken in co-operation with Dr. Elkin. Each plate has also 2 exposures on a pair of standard stars near *Jupiter*, the position-angle and distance of which have been determined with the heliometer. These standard stars will serve to determine the scale value and the orientation of the plate.

A great deal of labour has been bestowed on the determination of the errors of the scales of the photographic measuring apparatus and on the errors of *réseaux*. Some account of a portion of this work has been sent to Professor Pritchard. A large number of plates of the *Victoria* stars and of *Jupiter's* satellites have been measured.

Professor Auwers has completed his discussion of the 5,300 meridian observations of the *Victoria* comparison stars (made at 22 different observatories), and has communicated the results. The whole of the heliometer observations of the triangulation made at the Cape and Göttingen have been reduced at the Cape, those made at Yale have been communicated by Dr. Elkin, corrected for refraction, aberration, &c. The heliometer measures

of distance have been completely discussed and reduced to a common system, and then compared with the corresponding distances computed from the meridian observations.

For the determination of the 74 unknown quantities (viz. $\Delta\alpha$ and $\Delta\delta$ for each of the thirty-seven stars) the heliometer distances afford 175 equations, the position-angles 26 equations, and the meridian observations 74 equations. These equations are now formed, and their solution is only deferred pending a reply from Professor Auwers to sundry questions respecting details of his discussion of the meridian observations, as these details affect the weights of the equations.

The reductions of the meridian work, so long in arrear, have been rapidly pushed forward since the increase of the available computing force, sanctioned by the Lords Commissioners of the Admiralty. The reductions to apparent place are completed to the end of 1891, the examination of the Right Ascensions to the same date, and that of the North Polar Distances to the middle of September. One copy of the corrections to mean place is finished to the end of July 1891, the duplicate to September 1890.

The publication of the catalogue for 1885, otherwise complete, is only delayed on account of the necessity for a re-discussion of the N.P.D.'s in the light of recent investigations connected with change of latitude.

The results of the Cape Meridian observations of the Sun, *Mercury*, and *Venus*, to the end of 1890, have been communicated to Professor Simon Newcomb, for incorporation in the discussion of the constants of his new planetary tables.

The field work of the Geodetic Survey makes rapid progress. Major Morris, R.E., has completed the measurement of a meridian arc from Port Elizabeth to Kimberley, and H.M. Astronomer and Mr. Finlay have successively taken part in the measurement of a base line at Kimberley. Major Morris has completed the connection of this chain of triangles with the Kimberley base line, and is now engaged on a longitude chain of triangles connecting the Kimberley arc with Maclear's arc along the parallel of 31° south latitude. This arc, with a short latitude arc connecting the last-mentioned longitude arc (the Hanover longitude arc), at its middle point, with the longitude chain which connects Port Elizabeth with the southern triangles of Maclear's arc, will complete the field work of the Geodetic Survey of the Cape Colony and Natal. It is expected that this work will be finished by the end of August 1892, when immediate steps will be taken for its reduction and publication.

The meteorological observations made in the year 1890, at the observatory, have been printed, together with those taken in different parts of the colony, in the Report of the Meteorological Commission.

During 1891 thirty-six plates of the photographic *Durchmusterung* have been rephotographed.

Professor Kapteyn reports, under date 1891 November 8, with reference to his measurement of the plates of the Cape Photographic *Durchmusterung*, that about one hundred plates, including the last replicas, remain to be measured. The unexpected delay in completing the measures has been caused by the extreme richness of the regions, — 34° to — 57°. The actual work accomplished is as follows :—

From R.A. 19^h to 7^h all is complete except the zone — 53° to — 58°.

R.A. 7^h to 19^h all is complete except the zones

$$\begin{aligned} \delta &-53^\circ \text{ to } -58^\circ \\ &-43 \text{ to } -48 \\ &-34 \text{ to } -38 \end{aligned}$$

The total number of observations made up to the present time is about 750,000, without taking account of 86,000 made on the zones — 34° to — 57°, which were rephotographed and the original plates rejected. The two zones — 38° to — 42° and — 48° to — 52° have alone involved 265,000 observations. Up to the present time the work furnishes in all places for about 280,000 separate stars. The whole work will contain more star places than Argelander's *Durchmusterung* of the northern heavens, and will involve more than one million observations.

Armagh Observatory.

During the past year the 10-inch refractor has again been chiefly used for micrometric measures of nebulæ and neighbouring stars which have been observed on the meridian. The objects under observation are principally those of Schönfeld's second catalogue, which have not hitherto been observed with filar micrometers, while a limited number of objects have been entered on the working list in order to determine the personal equation between the Armagh results and previous measures. Owing to climatic difficulties, moonlight nights, and the long summer twilight, work of this kind can only progress very slowly.

In the autumn physical observations of *Jupiter* were made, particularly of the black spots in the northern hemisphere and of the new red spot.

The weather was very unfavourable on the night of the lunar eclipse of November 15, and only two occultations of faint stars were observed.

Cambridge Observatory.

The acquisition of the great refractor, the munificent gift of the late Mr. Newall, of Gateshead, will render this year memorable in the annals of the Cambridge Observatory.

Mr. H. F. Newall, M.A., Trinity College, son of the donor of the telescope, has enhanced the value of the gift by a large contribution to the expenses of removal, by himself superintending the re-erection, and by undertaking to work the instrument for five years.

The entire dome and mounting have been transported from Ferndene and erected in the field adjoining the Northumberland equatoreal. A spectroscope is to be provided from a grant which was made from "the Bruce Fund," through Professor E. C. Pickering. Sir H. Grubb is about to undertake some alterations to the driving clock. In the meantime some general investigations of the capacity of the instrument have been carried out, so far as the absence of clock-work will allow. A systematic series of photographs of the Moon have been taken with very short exposures, and the results show that a very fair image may be got on an ordinary sensitive plate set, roughly speaking, $\frac{1}{4}$ inch away from the visual focus, the focal length of the telescope being slightly under 29 feet. Preliminary measures have been taken by Vogel's spectroscopic method of the achromaticity of the object-glass, with very promising results.

About the usual amount of work has been done with the meridian-circle, except in the case of the zone stars, comparatively few of which required re-observing. The reduction of these observations, as far as Apparent Right Ascension and North Polar Distance, has been brought up nearly to date.

Wolf's periodic comet has been observed with the Northumberland telescope and square-bar micrometer on twenty-two nights, on which were obtained 147 comparisons with adjoining stars. Some of these stars require re-observing with the meridian-circle before their places can be relied on.

Several demands from other observatories, for places of stars included in our zone, have been met with promptitude; by far the largest of these was one made by the Astronomer Royal; in response the places of 791 stars, deduced from 2,819 observations, were furnished to him for the reduction of photographic zones.

The necessary preparations were made for observing the transit of *Mercury* on May 10, and the occultation of small stars during the total eclipse of the Moon on November 15. No observations, however, were made on account of the bad state of the weather.

The heaviest part of the work during the year has been the task of cataloguing the zone stars. The mean places for 1875·0 from each individual observation, to the number of 17,743, are already entered. This brings up the catalogue to the end of the

first eleven hours of Right Ascension. Another catalogue is also in course of preparation, which will give the place of each star deduced from the mean of all the observations of that star given in the larger catalogue; this has been done for the first two hours of Right Ascension.

A new volume of the observations is going through the press.

Dunsink Observatory.

The photographic work at this observatory with the 15-inch photo-reflector which was in progress at the beginning of last year was interrupted early in January for the purpose of altering the form of the clock, as explained in last year's report.

It was hoped by taking the motion direct from the spindle to obtain running sufficiently accurate for photographic work, and at the same time one of Grubb's electric slow motions in R.A. was applied. In this form, however, it was found that the clock was not powerful enough to drive the instrument when the accelerating key was down, and having tried an auxiliary weight, so arranged as almost to overcome the friction in the bearings of the polar axis—an arrangement which proved unsatisfactory—it was found necessary to increase the driving weight of the clock to nearly 200 lbs.

With this weight the running of the clock is very much improved, and there does not appear to be any periodic irregularity in the gear which connects the clock with the polar axis; but there are still occasional irregularities which necessitate uninterrupted watching, and render an exposure of even a quarter of an hour a very laborious task. It is possible, however, by close attention during the whole time of exposure, and in consequence of the beautifully smooth action of the slow motion in R.A., to obtain star images which, under the magnifying power employed in the microscope, appear sensibly circular.

In September the examination of the microscope supplied by Messrs. Troughton & Simms for measuring the photographs was commenced. This instrument is similar to the microscope supplied by the same firm for the Oxford University Observatory, except that the frame for holding the plate, which in the Oxford University instrument carries a 2-inch circular, is in our case adapted for a $3\frac{1}{4}$-inch square plate.

The screws of this instrument were examined in the usual way for periodic error and for differences of screw-value at different parts of the screw, and appear satisfactory, although in both respects the (H) horizontal screw is superior to the (V) vertical screw. In the case of the H screw the differences of screw-value are quite inconsiderable, except for a small part near the end of its range, where the error from this cause runs up to nearly half a second. The periodic errors are very small, and are represented by the formulæ—

$$+0''.048 \cos (u - 52^\circ\ 58') - 0''.030 \cos (2u - 28^\circ\ 28')$$

and

$$-0.161 \cos (u - 56\ 25) - 0.031 \cos (2u - 43\ 19)$$

for the H and V screws respectively.

In consequence of the interruptions of the photographic work necessitated by the alterations of the clock, by Mr. Rambaut's illness, which prevented his observing at night from April till August, and other causes, the number of plates exposed bears but a small proportion to what we hope to do in the future. On the whole there have been 55 plates taken, containing 136 exposures. Of these a considerable proportion are suitable for measurement. In particular, a photograph of the clusters in *Perseus*, taken on September 1 with two exposures of 10^m each, has occupied much time, both in measuring it and in investigating the methods and formulæ of reduction. We hope before long to be in a position to publish the results of the measures of this photograph, which are still in progress.

During the stoppage of the photographic work recourse was had to the working list of stars with large proper motion referred to in former reports. As in previous years, the meridian-circle and chronograph were used for this work.

In this connection there were 234 observations of R.A. and 186 of declination, 32 of collimation error, 8 of the errors of runs, 27 of level error, and 26 of the nadir point of the circle.

In addition there were 334 circle readings and 158 micrometer measures made with the meridian-circle, in connection with some experiments on the reflexion of light, which are not yet concluded.

Glasgow Observatory.

The operations at the Glasgow Observatory during the past year have consisted chiefly of meridional observations of telescopic stars, especially stars in Bessel's Zones, with the view of establishing the existence or non-existence of proper motion of sensible magnitude in cases wherein a comparison of star-places in the Glasgow Catalogue with previously observed places had left this question doubtful. It was intended to have the results published towards the close of last year, but circumstances have occurred which will cause a delay of a few months. It is to be hoped that the Scottish University Commissioners before concluding their labours will make some provision for promoting the efficiency both of the observatory and of the Professorship of Astronomy connected with it.

Due preparations were made for observing the total eclipse of the Moon of November 15, in accordance with the suggestions of M. Döllen, but the unfavourable state of the weather prevented their being carried into effect.

Liverpool Observatory, Bidston, Birkenhead.

The astronomical work has consisted chiefly in observations of stars with the transit instrument for the determination of clock errors. Preparations were made for observing the occultations of the stars in Dr. Döllen's list on the occasion of the lunar eclipse on November 15, but clouds obscured the Moon during the total phase.

Greenwich mean time has been communicated to the Port by the firing at 1 P.M. daily of the gun placed on the pier-head of the Morpeth Dock.

Two hundred and eighty-three marine chronometers have been tested at the observatory during the past year. We have no reason to suppose the thermal error, or correction due to change of temperature, remains constant for only a short period. In fact, our records prove that the reverse is the case.

The meteorological work has been continued as heretofore. No break has occurred in the records of the self-registering instruments.

Radcliffe Observatory, Oxford.

During the year 1891 considerable progress has been made in the preparation of a General Catalogue of Stars for zero points between 90° and 115° N.P.D.

A very approximate catalogue has been formed from the observations made during the years 1880–1890, both inclusive; and with these places the precessions and secular variations have been computed for the final catalogue for the whole of the stars, which number 5,363.

The North Polar Distances made in 1891 are completely reduced to mean place; the Right Ascensions will very shortly be ready for the formation of the Ledger and the Catalogue for the year.

The observations made in 1891 afford places for nearly a thousand additional stars; and the total number of stars included in the General Catalogue will be about 6,350. The whole of these stars have now been observed, with the exception of thirty, whose places will be secured in the earlier months of the present year.

The number of transits observed in 1891 has been 3,269, and the number of circle observations 2,780; but to secure these observations special watches have had to be arranged for during a part of the year.

The Sun and Moon have been observed with the transit circle at every opportunity.

With the Barclay equatoreal the last contact of the partial solar eclipse of June 6 was secured; forty observations of

fourteen double stars have been made; Encke's Comet was observed on August 12, September 10, September 30, October 4, and October 11; and Wolf's Comet was observed on four nights. The observation of the lunar eclipse of November 15 was prevented through cloud.

The meteorological observations have been continued as usual.

Oxford University Observatory.

During the past year the series of observations for the determination of the parallax of all stars of the second magnitude, conveniently situated for England, has been brought to a complete and, it is hoped, satisfactory conclusion. The results will be communicated to the Society at an early period.

All the plates necessary for the determination of the parallax of γ *Draconis* have been taken, and the measurements are completed. The observations extend throughout the year.

A long series of plates has also been completed for the parallax of the two very faint stars of comparison used in the determination of the parallax of α *Cephei*. The measuring of plates is commenced. The total number of photographs taken and measured for the purposes of the above computations much exceeds four thousand. The parallax of the second magnitude stars, referred to above, being completely finished, a group of stars bright and faint has been selected for the determination of their distances from the Sun, and it is not improbable that some interesting results may follow, owing to the fact of their being involved in nebulosity and having very nearly the same proper motions.

Very much time has been necessarily expended in the preparation of the new instruments to be used on the international chart of the heavens.

A considerable number of plates comprised in the zone assigned to Oxford have been completed.

The latter operations have been materially delayed by the necessity of examining the effects of wire-gauze screens in reducing the apparent brightness of stars by definite amounts, as proposed by a committee of the international chart. This method has not practically succeeded either at Greenwich, Paris, or Oxford. In consequence of this, a request was made to the Oxford Observatory to furnish charts and short catalogues of stars of the ninth and eleventh magnitudes, situated in convenient typical regions assigned by Professor Kapteyn. Six of these have already been circulated among the various observatories engaged in the work. These have required both time and attention to complete with available accuracy.

In the course of the observations made with the wire-gauze screens, several interesting and unexpected results have been

obtained. These have been communicated to the French Academy, and published by them in their *Comptes Rendus*.

Mr. Plummer was deputed to represent the University Observatory at the International Congress in Paris. By his long experience in stellar photography he was enabled to render valuable service.

Photographic plates have been taken, and photometric observations of the *Nova* in *Auriga* have been made whenever the state of the sky has permitted.

Temple Observatory, Rugby.

Mr. Highton has continued the measurement of position and distance of double stars with the $8\frac{1}{4}$-inch refractor, and Mr. Seabroke has measured the velocity of motion of stars in the line of sight with the spectroscope on the 12-inch reflector.

A 15-inch silvered glass mirror, of 45 inches focus, has been mounted recently for the photographing of faint objects, and as soon as the weather permits operations will be commenced.

There has been a much larger attendance than usual of members of the School during the autumn months, so that our original work has been reduced in quantity.

Dr. Common's Observatory.

During the past year a new 5-foot mirror has been made for the telescope. This piece of glass has proved to be almost—if not quite—perfect, and the mirror is a most excellent one.

Some very fine photographs of nebulæ and the Moon have been taken, that will be laid before the Society.

A new grating spectroscope has been fitted to the 5-foot.

Work on plane mirrors has been carried on in the workshop.

Mr. E. Crossley's Observatory, Bermerside, Halifax.

As in past years, the work of this observatory has been chiefly the measurement of double stars, the observation of the phenomena of *Jupiter's* and *Saturn's* satellites, and occultations of stars by the Moon. Meteorological observations are taken daily at 9 A.M. and 3 P.M., and reports sent to the Registrar-General, Mr. Symons, and the local Sanitary Department. A number of double-star measures and the year's work on the satellites of *Jupiter*, &c., have been communicated to the Society. About one thousand measures of double stars were made in January, February, and March; these and all the measures made since 1881 will shortly be ready for publication.

The figuring of the 3-foot (B mirror) has been completed by Sir H. Grubb. It is a great improvement on the A mirror, with which Dr. Common took the photographs of the Moon, &c., in the possession of the Society. Many photographs of the Moon and other objects have been taken with the mirror, but, owing to the very bad observing weather throughout the autumn and early winter, no results of special interest have yet been obtained.

Wolsingham Observatory. (Rev. T. E. Espin's.)

The sweeps for stars of the third and fourth types have been continued as in previous years. The total number of new third-type stars detected is 120. Only one star of the fourth type has been found, this is—

D.M. +31°·1388 R.A. 6h 32m 46s·7 Decl. +31° 35′·1 8·1 (1855)

The presentation of the charts of Argelander's Northern Heavens by Mr. T. W. Backhouse has given the opportunity of systematic zone work with the spectroscope, and during December seven hours of R.A. were examined at decl. +55°, and 31 third-type stars detected. In all five new variable stars were discovered during the year, they are—

(1)	...	R.A.	4h	26m	4s	Decl. +65°	52′·8	(1855) discovered	Mar. 2
(2)	D.M. +68°·398	„	5	25	22	„ +68	42·5	„ „	Feb. 16
(3)	...	„	5	32	42	„ +31	57·5	„ „	Jan. 31
(4)	D.M. +36°·3852	„	19	59	6	„ +36	24·8	„ „	Sep. 10
(5)	...	„	20	11	54	„ +49	29·7	„ „	Sep. 10

Of these, Nos. 1, 3, 4 have a third-type spectrum; No. 2 is remarkable from the enormous size of the bands—unfortunately it was not observed at a maximum in 1891; No. 5 is probably type IV. Dr. Wolf's photographs of the *α Cygni* regions were compared together, and also with the charts of Argelander, and those stars marked which showed any large difference of magnitude on the photographs. Seven evenings in the autumn were devoted to the observation with the spectroscope of these objects, and 171 stars were thus examined. The variation of the star D.M. +39°·4208 is confirmed by the photographs. Two nights were also devoted to a careful examination of the great *Perseus* cluster, with the object of definitely identifying the red stars therein. The meteorological instruments presented by Miss E. Brooke have been read daily. Alterations in the roof had to be made to fix the anemometer and sunshine recorder, and these were not finished till the middle of April. The instruments were then fixed with as little delay as possible. The observations of thunderstorms,

extending over a period of nearly twenty years, will shortly, it is hoped, be ready for the press; their publication has been delayed mainly for the purpose of completing some experimental work which opened up some unexpected results.

Rousdon Observatory. (Mr. C. E. Peek's.)

The establishment is maintained in efficient working order, and the observation of long-period variable stars is regularly carried on.

During 1891 observations were made on 167 nights, and 441 determinations of magnitudes were obtained, involving about 2,200 comparisons of the variables with stars of standard magnitude.

The working list was somewhat modified by the introduction of several circumpolar variables and the withdrawal of a few less favourably situated stars. The whole of the sixteen long-period circumpolar variables recommended by Professor Pickering as worthy of continued study are now regularly observed, the greater number having been under observation for the last six years.

In several cases a slight nebulosity has been suspected at minimum, and the attention of observers is requested to this point.

The usual observations for clock rating have been taken.

The equatoreal has a $6\frac{1}{4}$-inch O.G.

Mr. Isaac Roberts's Observatory, Crowborough Hill, Sussex.

Photographic work has been steadily pursued at this observatory during the year ending December 31, 1891, and Crowborough Hill is found to be a more favourable locality than Maghull for this work.

The months of February, April, May, and September had the greatest number of clear nights. In the course of the year 196 photographs of stars, nebulæ, and clusters were obtained with exposures varying between 30 minutes and four hours respectively (besides many others with shorter exposures), enlargements of some of which, accompanied by explanatory notes, will in due course be submitted to the Society. Twenty-nine of the photographs were taken, with exposures of 90 minutes each, of that part of the sky indicated by Professor Forbes, in which he thought a planet might be found beyond the orbit of *Neptune*, but as there are yet to be taken two photographs to cover the whole of the region indicated, it is necessary to defer the report I shall have to make concerning Professor Forbes's hypothesis.

In the description given of this observatory in the *Monthly*

Notices (vol. li. p. 118) it is stated that the dome was constructed with two slits so as to permit both the reflector and the refractor being used simultaneously, but in practice it was found that the disadvantages of this plan outweighed the advantages, inasmuch as the division between the slits (two feet in width) being continuous over the vertical axis of the dome obscured part of the sky about the zenith during nearly two hours in Right Ascension. The dome has consequently been altered, and it has now one slit 4 feet 1 inch in width, extending from the horizontal continuously to 18 inches beyond the zenith.

Birr Castle Observatory. (*The Earl of Rosse's.*)

There is nothing special to report on the work of Birr Castle Observatory during the past year. Lord Rosse was absent, either abroad or in England, almost continuously for the first seven months, and the weather, which may have been about up to an average till his return, certainly changed for the worse afterwards. It was intended to obtain measurements of lunar heat during the eclipse of November 15, but only glimpses of the Moon through clouds and drift were obtained. The further prosecution of this work at every opportunity is kept in view.

Meteorological and other routine work has been carried on as usual.

Mr. W. E. Wilson's Observatory, Streete, Co. Westmeath.

During the past year the 2-foot reflector has been remounted by Sir H. Grubb. The old mounting was found to be too weak and unsteady for any photographic work, and it was therefore decided to have the instrument entirely remounted, and provided with driving clock and electrical control of the same type as the standard photographic telescopes. The instrument will be quite finished and ready for work early this year.

The photographic photometer described at the meeting of the Society on January 8 is still in Sir H. Grubb's hands, and as soon as it is received will be used in some work on star magnitudes.

The experiments on solar radiation, which have been in progress for some years, will be resumed with the aid of a large siderostat kindly lent by the Royal Society.

Adelaide Observatory.

During the past year the staff have been employed in re-observing the Weisse stars from the Equator to 15° south, including other stars not in the catalogue, down to the tenth magnitude.

This undertaking was commenced on April 27, Mr. Cooke, the first assistant, having special charge of it. Each star will be observed three times.

The following will show what has been done during 1891 :—

No. of observations with Transit Circle in Right Ascension ...	3,204
„ „ „ in Declination	2,342
No. of observations of Nadir	76
No. of determinations of Level error	91
„ „ Collimation	93

The reductions are well forward, and progress catalogues will be published from time to time. In addition to this, during the course of the year, careful determination has been made of the errors of division and flexure, besides special observations for colatitude.

It should be mentioned that a new transit clock by Frodsham has been added to the equipment; and the old clock has been converted into a mean-time clock, and is now being fitted to drop the time-ball at the semaphore, which has hitherto been dropped by hand contact. It is intended shortly to drop time-balls at Port Augusta and Port Pirio.

The mean-time clock will also transmit time signals to the different post and telegraph offices throughout the colony. The clocks at Parliament House are synchronised by means of hourly signals transmitted by the tower clock at the General Post Office, which is kept within a few seconds of mean time.

The equatoreal has been principally employed on *Jupiter*; occultations, eclipses, and transits of its satellites; and drawings, of which a very large and continuous series has been made by Mr. Sells.

In meteorology we have 350 stations, spread all over the colony, from Port Darwin, on the north coast, southwards, at which the rainfall is recorded. The returns are published monthly.

Weather reports are exchanged every morning with each of the neighbouring colonies, including Tasmania and New Zealand. These reports emanate from no less than 72 stations—viz. 13 in Queensland, 15 in New South Wales, 11 in Victoria, 17 in South Australia, 8 in West Australia, 5 in Tasmania, and 3 in New Zealand—and every telegraph office in the colony transmits a report, giving direction and force of wind, state of weather, and rainfall at 9^h A.M. From these are compiled a tabular statement and general report, an isobaric map, and a forecast is issued for the ensuing 24 or 48 hours, all of which are exhibited in the hall of the General Post Office and other places, as well as being published in the daily papers. The Goverment Astronomer is usually responsible for the forecasts.

In conjunction with Commander W. Usborne Moore, R.N.,

C.M.G., of H.M.S. *Penguin*, telegraphic determinations of the difference of longitude between the Adelaide Observatory and Roebuck Bay, Fremantle, and Port Darwin have been made.

The past year has been very dry—nearly the driest on record. The rainfall at Adelaide was 14·005 inches, or 6·563 inches below the average.

Hong Kong Observatory.

During the past year the time-ball was dropped as usual at 1 P.M., but there were many failures, and the signal was not so accurate as previously, owing to lack of skill on the part of the new assistants. A new standard clock has been received from Mr. James Brock, of 64 George Street, Portman Square, London. There is a very heavy pendulum swinging in an arc of over four degrees, which lessens the barometric co-efficients, but it is, as usual, over-compensated for temperature, the maker having left the zinc too long, so that it might be subsequently cut to the proper length. A mercurial compensation was ordered, and would have been preferred. As we have now two standard clocks, kept in rooms of different temperatures, it is to be hoped that great accuracy will be attained next year.

Observations of occultations of stars and phenomena presented by *Jupiter's* satellites were made with the Lee equatoreal, and shooting stars were also observed by the Director.

Absolute magnetic observations are now again made monthly.

Local meteorological observations and researches have been continued at the observatory and at the Peak. Reports were received from about forty stations in the Far East, and extracts have been made from log-books of vessels having encountered bad weather. These returns are at present being reduced for the construction of daily weather maps, by aid of which the typhoons of the past years will be investigated up to date. Daily weather reports and telegraphic storm-warnings were issued as usual.

The seventh annual volume was issued last spring, and the next volume is nearly ready for press. A third edition of the "Instructions for making Meteorological Observations in China" and "The Law of Storms in the Eastern Seas" have been issued. A considerable portion of the Director's time is taken up by furnishing information in response to inquiries about meteorological features, the deviation of the compass on board ship and similar matters. Instruments are also frequently sent to the observatory for verification, especially clinical and other thermometers.

Melbourne Observatory.

The work of the Melbourne Observatory for the year 1891 has varied little from that of former years. As usual the chief attention has been paid to the meridian work, which has been

considerably heavier since February last, owing to the Melbourne Observatory having undertaken to observe the guide stars for the photographic zones 10° to 14° south; these stars to the number of 922 have been observed in both co-ordinates at least three times; besides these a few stars have had their places determined for the survey department of New South Wales; a small number of stars compared with comets have also been observed. As regards the guide stars, in nearly all the instances stars of the required brightness have been found, and within the adopted limits from the centre of each plate. In a few cases, however, it was necessary to go outside the limits for a star of the required brightness, and in others the stars, although registered in Argelander's *Durchmusterung* as of the ninth magnitude, seem to be much fainter at the present time. Altogether this year 4,824 observations of Right Ascension and 3,193 of polar distance have been obtained with the new transit circle of eight inches aperture; in addition to which, owing to the abnormally cloudy weather in the spring season, about a hundred observations had to be taken with the old instrument of five inches aperture. It is intended to devote next year to the observation of the guide stars for the circumpolar photographic zones which have been assigned to this observatory.

Preparations and training for the Melbourne share of the photographic charting of the heavens have also added largely to the work. The photographic telescope arrived on 1890 December 27, and its erection was completed in January. The experimental work and training occupied the time of a part of the staff for many months, and now that work has actually been commenced it is found that during its progress the staff will be barely sufficient to cope with it, in addition to the increased meridian observing.

Unfortunately the astrographic work is now at a standstill for want of plates, the manufacturers in England having failed to keep up the supply. The early arrival of a consignment from M. Lumière of Lyons is now expected, which will enable the staff to resume without any serious loss of time.

The pressure on the staff has interfered with the extra meridian work, both with the great telescope and smaller instruments.

The routine meteorological and magnetic work was carried on continuously during the year, and photographs of the Sun were taken on every fine day with the photoheliograph.

As regards the preliminary work of the photographic charting, a great deal has been done in connection with determining the relations between photographic and photometric magnitudes with various makes of plates, varying exposures, and different kinds of fine nights. The results indicate numerous difficulties, and lead to a conclusion a little at variance with the later decisions of the Congress. It is found that, for the catalogue plates, to get safely measurable images of stars an exposure of 10^m is necessary; that a safely measurable image is never less than

3·75 mm. in diameter, and that to gain one magnitude (ratio 2 512) the time of exposure must be increased 3·16 times, or to gain two magnitudes it must be increased ten times. To account for these results being somewhat at variance with those adopted by the Congress, it may be suggested as being due to either different climatic conditions or some optical instrumental constant. The number of measures upon which the results depend is very considerable.

Natal Observatory.

The principal series of observations in progress at the observatory is the comparison of the declination deduced from observations made at the observatories in the northern and southern hemispheres, by a comparison, by Talcott's method, of the zenith distances of northern stars and southern circumpolars. During the year a number of additional observations have been obtained and reduced.

The work of observing equizenith distance stars, for determining the latitude of the observatory, has been brought to a conclusion. There have been obtained 1,022 observations of thirty-five pairs of stars. They have all been reduced and tabulated. Accurate places for all the stars used have been deduced from all the modern meridian observations that were available. The whole work is now completed and awaits publication.

At last there has been completed the work of comparing the entire mass of Greenwich meridian observations of the Moon, made during the years 1851–1888, with the theory forming the basis of Hansen's Lunar Tables. The results from these four thousand observations have been fully discussed, and the corrections deduced which are required by Hansen's Tabular Coefficients. Auxiliary tables are now being formed, founded on the corrections thus deduced, and the whole work is being prepared for publication as a memoir.

The final touches are also being put to the discussion of the observations of the position of the lunar crater Murchison A, made at the Arkley Observatory in the years 1879–1884, and at the Natal Observatory during the years 1883–1886.

Some, but not much, further progress has been made in preparing for publication two memoirs on the irregularities in the motion of the Moon, due to the perturbations of the planets, the first affording an investigation of the theory, and the second a numerical calculation of the value of some thirty-five terms. As the actual mathematical work in this complex investigation is completed, it is to be regretted that so much delay should ensue in the publication. Unfortunately the writing out of such work for the press cannot be done in little fragments in spare hours, and the heavy pressure of other duties has left no time for systematic work. The results are important, as they show that the method employed by Delaunay and his successors in their

determination of the values of coefficients of this kind is, as already stated, entirely incomplete, so that none of the values that have been made known are accurate.

Further progress has also been made in the reduction of the Durban Tidal Records.

A good deal of astronomical work has now accumulated at the observatory, and it is in contemplation to publish a volume of Observations and Results.

In July Mr. Grant resigned his position as Astronomical Assistant, and since then nearly the entire series of routine observation, calculation, and reduction have been made by the young ladies who have for some years so zealously aided in the work of the observatory.

Sydney Observatory.

At Sydney the year has been unusually cloudy and wet, and generally unfavourable for observations. The latter part of the year has been most unsuitable for photographic work, owing to the prevalence of thin cloud or haze.

A very fine micrometer for the pointer telescope has been made in the observatory, and a number of minor conveniences applied to the photographic telescope, including an improved box for charging the sensitive plates, which enables the operator to do the work better and more quickly.

It has been decided to publish a full description of the star camera, and the publication is now in a fair way of completion.

With the transit circle 1,330 transits in R.A. have been taken, comprising 714 stars observed in R.A. only, 616 stars in R.A. and N.P.D.; 165 of these belong to the photographic zone.

Azimuth has been determined 82 times, Collimation 280 times, Levels 365 times, Nadir 365 times.

The 1889 Catalogue has been completed; the 1890 Catalogue has been formed, and reduction to 1890 partly finished. The 1891 computations are complete, preparatory to formation of catalogue.

All unpublished R.A. and N.P.D. work has been examined to the end of 1890.

Four nights were devoted to determination of the longitude of Bourke Town, Gulf of Carpentaria, in conjunction with the trigonometrical survey staff of Queensland.

The Circle B was examined thoroughly at every degree.

The equatoreal work during the year includes measures of 93 double stars, made on 80 nights, comprising 590 measures of angle and 590 measures of distance.

Search was made for comet *Barnard* in May on two mornings without success, and for comet *Tempel-Swift* on two evenings with no result. Comet *Barnard* (Oct.) was observed on three evenings, and 62 comparisons made with 4 stars.

The transit of *Mercury* was observed on May 10.

The average definition during the year was very poor, fifty-six nights only being noted as fine; on fifteen of these, however, definition was so bad that nothing could be done.

The computations for the reduction of the double-star work are completed and ready for publication. The comet observations have been published.

Pending the final meeting of the Committee in Paris on 1891 March 31, to decide details of photographic work, the work in connection with the Milky Way has been extended, and the great rift across it in *Argo* photographed, with the result that the dark places do not appear on the photographs. The star camera has been used to investigate important regions, and the densest part of *Nubecula Major*, *η Argûs*, the Trifid Nebula, &c., with remarkably good results. In the neighbourhood of *η Argûs*, in parts specially examined by Sir John Herschel, the camera shows ten times as many stars, and entirely new features of nebula with $5\frac{3}{4}$ hours' exposure.

A part of the year has been devoted to a thorough re-examination of the focus, with the lens supported on three points, as by the maker, and supported all round. The images are slightly better with continuous support, but the 3-point support was adhered to, because other star cameras are so supported. The resulting focus gives good measurable images of stars 3″ in diameter, some as low as 2″·85, probably smaller in clear, steady weather; but, as already stated, the weather during the focus experiments (*i.e.* October, November, and part of December) has been very bad.

Fifty catalogue plates have been taken, but some of these may have to be done again, owing to hazy weather.

Three *réseaux* have been obtained from M. Gautier, of Paris, beautifully made; but from some chemical change the silver is apt to develop troublesome *pin holes*, easily mistaken for stars.

The wire screen intended to facilitate the determination of 11 mag. stars was not received until October.

A volume, containing silver prints of the southern part of the Milky Way, has been published and distributed. Other papers in connection with star photographs have been published in the *Monthly Notices*, and *Proceedings of the Royal Society of New South Wales*.

Photographs were attempted whenever there was a break in the clouds; in all on 143 nights, but only fifty-two of these gave satisfactory results. October, November, and December were almost useless for the star camera, owing to thin haze—hot-weather haze. Exposures have been given on some of these nights up to thirty minutes, without getting a trace of 11 magnitude stars.

The weather-chart service has been maintained and improved; considerable improvement has also been introduced into the printing. The daily issue of two editions has been kept up for

public convenience, and the service is appreciated by the public. The maps are bound in monthly parts, and distributed to other observatories.

The general meteorological work has been kept up. The monthly reports up to the end of October have been printed and distributed. The rain report for 1890 has been seven months in the printer's hands. The volume of general meteorological results for 1889 has been printed, and is ready for distribution. All the reductions for 1890 are complete, and those for 1891 are in a forward state.

The total number of meteorological stations is now 1,238.

Mr. Tebbutt's Observatory, Windsor, New South Wales.

Notwithstanding that much cloudy weather prevailed during the early part of the year 1891, a considerable amount of work has been done. The transit instrument was employed on 175 nights, and 975 transits of stars, not exceeding 40 degrees of declination, were observed for local time only. Besides these observations many other meridian transits were observed for various purposes. The observations for instrumental errors have been 385 for level, 50 for collimation, and 186 for azimuth. No adjustment of the instrument was made during the year. At the beginning of the year the western pivot was 7″ too high, but it gradually fell till July, the coldest month, when the axis became level. The pivot then rose gradually, and recovered its former value at the close of the year. The collimation and azimuth errors have been as steady as in former years. The chronometer rate has been very satisfactory.

The following extra-meridian observations have been made with the 8-inch and $4\frac{1}{2}$-inch equatoreals :—

Lunar occultations of stars, comprising forty-five disappearances, eleven reappearances, and one graze. The satisfactory result in this department is, in a great measure, due to the interest of Mr. R. T. A. Innes, of Sydney, who has kindly supplied the observatory with the prediction calculations of *Nautical Almanac* stars for the last eleven months of the year. Clouds, unfortunately, prevented the observation of the occultation of *Mercury* in daylight on December 3. Lunar occultations of stars are systematically observed here, in order specially to provide data for Professor Newcomb's investigation of the Moon's motions.

The observed phenomena of *Jupiter's* satellites are classified thus :—

Transit Ingress, I. 1, II. 2, III. 1. Transit Egress, I. 6, II. 3, III. 2. Occultation Disappearances, I. 4, II. 1, III. 1. Occultation Reappearance, IV. 1. Eclipse Disappearance, II. 1. Eclipse Reappearances, I. 3, II. 4, III. 1, IV. 1. Physical observations of some of the satellites were also made during their transits.

The transit of *Mercury* of May 9–10 was pretty well observed in both phases, particularly at egress.

Twelve excellent filar micrometer comparisons of *Venus* and *Jupiter* at their conjunction on April 7, and 107 similar comparisons of *Ceres* and neighbouring stars, between declinations $-26°$ and $-28°$, on August 15, 16, 17, 18, 19, 20, 30, 31, September 1, 2, 3.

Sixty-eight square bar micrometer comparisons of Comet I. 1891 (Barnard-Denning) on June 4, 11, 12, 13, 14, 29, July 2, 3, between declinations $-37°$ and $-47°$, and 105 of Wolf's periodical comet on October 9, 11, 30, 31, November 2, 3, 4, 7, December 17, 20, 21, 25, 26, between declinations $+10°$ and $-15°$.

Measures of the double stars *p Eridani*, *Lalande* 4219, *α Centauri*, 39 *Ophiuchi*, *κ Coronæ Australis*, *Brisbane* 6556, *h* 5075, and *γ Coronæ Australis*.

Determinations of the magnitudes of *η Argûs* and *R Carinæ*. No sensible change has taken place in the lustre of the former during the year, and a determination of the maximum (5·5 mag.) of the latter was obtained in March.

In addition to the work thus enumerated many observations have been made for determining constants in connection with the larger equatoreal. The 9^h A.M. meteorological observations have been carried on with great regularity, the past year being the twenty-ninth in this department of observation. The printed abstracts for 1886, 1887, 1888, 1889, and 1890 are now ready for distribution.

Finally, the instruments continue in good condition, and the library, which has now assumed fair proportions for a small establishment, continues to be enriched by many valuable presents from Colonial and foreign scientific institutions. This part of the report is very gratifying to the proprietor and encourages him to greater efforts in his labour of love.

Notes on some Points connected with the Progress of Astronomy during the Past Year.

Discovery of Minor Planets in 1891.

The past year has been the richest on record as regards the discovery of minor planets, no less than twenty-one having been added to the list, as compared with seventeen in 1875, twenty in 1879, fifteen in 1890.

The following is the list of discoveries:—

No.	Name of Planet.	Date of Discovery, 1891.	Discoverer.	Place of Discovery.
303	Josephina	Feb. 12	Millosevich	Rome
304	Olga	14	Palisa	Vienna
305		16	Charlois	Nice
306	Unitas	Mar. 1	Millosevich	Rome
307		5	Charlois	Nice
308		31	Borelly	Marseilles
309	Fraternitas	Apr. 6	Palisa	Vienna
310		May 16	Charlois	Nice
311		June 11	,,	,,
312		Aug. 28	,,	,,
313	Chaldaea	30	Palisa	Vienna
314		Sept. 1	Charlois	Nice
315	Constantia	4	Palisa	Vienna
316		8	Charlois	Nice
317		11	,,	,,
318		24	,,	,,
319		Oct. 8	,,	,,
320		12	Palisa	Vienna
321		15	,,	,,
322		Nov. 27	Borrelly	Marseilles
323		Dec. 22	Wolf	Heidelberg

It has been computed that 306 and 313 will each be at least 9·5 magnitude in favourable oppositions; 318 is interesting from

the almost exact commensurability of its period with that of *Jupiter*. From observations on September 24, October 9, October 21, Berberich deduces a period equal to *Jupiter's* $\div 1{\cdot}9987$.

Palisa on August 14 discovered what was for a time supposed to be a new planet, but on examination it was found to be identical with (149) *Medusa*, discovered in 1875, but not observed since.

It is still uncertain whether the planet discovered by Borrelly on November 27 may not be identical with (156) *Xanthippe*, discovered by Palisa in 1875, but not observed since that year.

323 is interesting as being the first new asteroid discovered by photography; another asteroid registered itself on the same plate but was found to be identical with (275) *Sapientia*.

296 has been named *Phaëtusa*, 297 *Caecilia*, 298 *Baptistina*, 299 *Thora*, 300 *Geraldina*, 301 *Bavaria*, 302 *Clarissa*.

A. C. D. C.

The Comets of 1891.

Exclusive of the comets visible at the end of last year, the following comets have been under observation :—

(*a*) Discovered by Mr. Barnard at the Lick Observatory on March 29, and independently by Mr. Denning, of Bristol, on the following night. The comet was tolerably bright at the time of its discovery, having a tail 30′ long. It increased in brilliancy throughout the following months, but its rapid southerly motion soon prevented observation in the northern hemisphere. It was seen at the Cape in the middle of June, and at Cordoba in July, but appears to have been very faint and difficult to observe. The orbit, which is not definitely determined, is probably parabolic.

(*b*) A reappearance of Wolf's comet of 1884. First seen, but the observation not completely verified, by Dr. Spitaler, of Vienna, on May 1, and certainly seen by Mr. Barnard, with the 12-inch equatoreal of Lick, on May 3. The theoretical brilliancy of the comet at this date was slightly greater than at the time of the last observation in 1885, by Professor Young at Princetown. This interesting comet can make a very close approach to *Jupiter*, and in 1875 the perturbations by that planet were so great that an altogether new orbit resulted. During the last revolution, however, the perturbations have not been heavy, and the computations of Drs. Thraen and L. Struve gave a very close approximation to the actual place of the comet.

(*c*) A return of Encke's comet. Dr. Backlund, of Pulkowa, had prepared an approximate ephemeris to aid the discovery, but, not being able to take the full effect of per-

turbation into account, feared that the true path might differ some minutes from that predicted. When discovered by Mr. Barnard on August 1, however, the error of the ephemeris was only about 2′ in the arc of a great circle. The comet passed through its perihelion on October 18, and the apparent path of the comet is not favourable for post-perihelion observation.

(*d*) A return of the periodic comet known as Tempel$_3$–Swift, first seen in 1869, and again in 1880. The peculiarity of this comet is that the return to perihelion, with a period of five and a half years, is effected under conditions alternately favourable and unfavourable to observation. Consequently, in 1886 the comet was not seen, and the difficulties of prediction at this return were proportionately increased. M. Bossert prepared an ephemeris with very great care, bringing up the perturbations from 1880, and by this means Mr. Barnard was again successful in seeing the comet, though the perihelion passage, being about two and a half days in error, the observed place differed considerably from that predicted. Mr. Barnard saw the comet on September 27, and it was independently detected by Mr. Denning on September 30. At this time the theoretical brilliancy of the comet was nearly the same as that when the comet was last seen in 1869. This comet passed through its perihelion on November 17, and is still under observation.

(*e*) On October 3 Mr. Barnard discovered a telescopic comet in the constellation *Argo*, and moving to the south. The great southern declination, combined with its direction of motion, prevented observation in the northern hemisphere. The diminishing brilliancy, and the rather unfavourable position with regard to the Sun, are likely to prevent this comet being adequately observed, but the orbit, still imperfectly known, is probably parabolic.

It is impossible not to recognise the important service which Mr. Barnard has rendered to the section of cometary astronomy.

Among the more interesting contributions to cometary literature have been the discussion of the orbit of Comet, 1882, II. (the great September comet) by Dr. Kreutz, of Kiel, and an inquiry into the suggestion of cometary capture by planetary perturbation from M. Callandreau, of the Paris Observatory. In the former of these Dr. Kreutz returns to a subject which he had previously considered. After an elaborate investigation, in his first paper, of the form of the orbit, Dr. Kreutz had concluded that the centre of gravity of the comet coincided with one of the five nuclei, into which it will be remembered the head of the comet subdivided itself. The point selected by the

author was the nucleus (2), the point (1) being the condensation farthest from the tail. Further discussion, in his second paper, has now led Dr. Kreutz to the conclusion that it is impossible to localise with precision the centre of gravity of the comet, which he would now place between point (2) and point (4). The observations anterior to the separation of the general nucleus are equally well represented by an orbit based on the third as on the second point of condensation; and, from the character of these orbits, the author indicates that the division of the nucleus has been accompanied by a diminution of the semi axis-major, and that if, as is probable, the disintegration of the nucleus did not modify the position of the plane of the orbit, the comet entered into our system with a period of revolution between 770 and 1,000 years; but this uncertainty renders it impossible to trace the appearance of the comet in any historical records.

Dr. Kreutz also discusses the cause of the division of the nucleus, and rejects the hypothesis which would attribute it to the action of the solar atmosphere, suggested by the close approach this comet made to the Sun. A very small alteration in the velocity of the different parts of the cometary nucleus, roughly one-five-hundred-thousandth of the whole, would be sufficient to explain the rupture; and, considering the spectroscopic modifications which the nucleus exhibited at the time of the perihelion passage, it is not improbable that an adequate explanation may be found in the internal constitution of the comet itself. A force emanating from the centre of the nucleus, and extending itself regularly in all directions, would, if sufficiently great, produce an effect similar to that which has been observed.

In the other contribution mentioned above, M. Callandreau, following a line of investigation pursued by M. Tisserand, has examined the conditions which the action of planetary influence can have upon a comet moving in a parabolic orbit, and, in particular, how far the perturbations of *Jupiter* can explain the existence of a family of periodic comets of short period, possessing the characteristics with which we are familiar. He finds that the fact of direct motion, of the coincidence of the aphelia with the orbit of *Jupiter*, of the absence of hyperbolic motion, can all be explained by supposing the comet, originally approximately parabolic, to have encountered the sphere of *Jupiter's* activity at a particular angle with the planet's radius vector. On examining the orbits of all the known periodic comets M. Callandreau finds only one whose orbit apparently contradicts this theory of cometary capture. This comet is Encke's, and the anomaly is explained by supposing that its introduction into the solar system is due to the action of some planet inferior to *Jupiter*.

This subject has also received attention at the hands of Professor Newton, in the *American Journal of Science*, and if some

difficulties still remain unexplained, such as the large number of periodic comets—a number larger than the theory of chances suggests—much has been done to remove what was vague and unsatisfactory, and to bring the hypotheses within the range of extreme probability.

Total Solar Eclipses.

There have been no total solar eclipses of importance in the last two years, but several reports of the pair in 1889 have been published. Both the Washington University eclipse party and the Lick Observatory party have published their accounts of the eclipse of January 1, 1889, and the photographs have been beautifully reproduced by the Smithsonian Institution; and the Lick Observatory account of that of December 22, 1889, has also appeared. A comparison of the published photographs shows clearly the change of the corona between January and December as pointed out by Mr. Wesley (Observatory, No. 160), the longer rays of which are all definitely equatorial in January, but show a tendency to sweep round towards the pole in December; and this is precisely in accordance with the change to be expected during a return towards maximum Sun-spot activity.

The Washington report for January 1, 1889, contains reproductions of four negatives and of a drawing made from all the negatives; also of drawings by Professor Engler and of one by Señor Valle, who shut out the inner corona with a disc, and represents streamers of 7° or 8° in length. The enormous length of these streamers, as seen in favourable conditions, has now been confirmed at several eclipses, and it is to be hoped that the question of the possibility of photographing them may be soon answered more satisfactorily.

The report of the Lick party for January 1 contains only one small silver print of the corona with several diagrams drawn from the negatives, in some of which the actinic intensity is represented from measurements of the photographs; but the Smithsonian Institution have reproduced in all nine negatives on a uniform scale; so that there is no lack of material for discussion.

The Lick report for December 22, 1889, contains prints of three negatives.

No remarkably new conclusions are drawn by the observers. There are at present two rival American theories of coronal structure—one due to Professor F. H. Bigelow, and the other to Professor J. M. Schaeberle. In a paper printed by the Smithsonian Institution the former contends that the streamers follow the lines of force of a certain distribution of electric potential; in the Lick Observatory report for December 1889 Professor Schaeberle compares the photographs of coronas with those of a

model globe with straight spines, arranged in a certain way, and finds a satisfactory resemblance. But it is necessary in the latter case to establish an annual variation of the corona, for which the evidence seems incomplete.

Professor Harkness's work on the Co-ordination of Astronomical Constants.

"It has been customary to endeavour to determine the solar parallax as if it were an independent constant, and the result is a mass of discordant values, all of which are more or less affected by constant errors, and none of which command anything like universal assent. But, in truth, the solar parallax is not an independent constant." It is entangled with the lunar parallax (P), the constant of luni-solar precession ($\mathfrak{P}$), the constant of nutation ($\mathfrak{N}$), the parallactic inequality of the Moon (Q), the constant of the Earth's lunar inequality (L), the constant of aberration (d), the light-equation (θ), the velocity of light (V), the mass of the Earth (E−M), the mass of the Moon (M), and the compression of the Earth (ϵ); and "it should be determined simultaneously with all these quantities by means of a least-square adjustment."

Professor W. Harkness, therefore, determined to undertake this very heavy piece of work, and the results appear in an appendix to the *Washington Observations* for 1885, under the title, "The Solar Parallax and its related Constants, including the Figure and Density of the Earth." His first care is to collect all the observed values of the quantities to be dealt with, and this compendium alone would render the work valuable. He adopts a single mean value in each particular case by a rather rough-and-ready process, which is possibly as good as any more elaborate method of weighting, but which is certainly open to criticism. These selected means are his raw material, and are to be submitted to the beautiful machine known by the name of least squares. The machinery works smoothly and satisfactorily in the skilful hands of Professor Harkness, and his definitive results are perhaps the best that can be obtained from his interpretation of the observations. The general result is that of the twelve independent variables selected above, the mass of the Moon was most in error, the probable error of the new determination being reduced to one-tenth of its previous value by the least-square solution. Important alterations are also made in Q, θ, and E; and next in order come the solar parallax and the nutation. The other constants are not seriously affected. The final table of definitive results for the epoch 1850·0 is as follows:—

Quantities.	Observed values.	Corrections by adjustment.	Adjusted values.
p	$8''.834 \pm 0''.012$	$-0''.0249$	$8''.8091 \pm 0''.0057$
P	3422.69 ± 0.17	-0.15	3422.54 ± 0.13
$\mathfrak{P}$	50.3570 ± 0.0035	$+0.0001$	50.3571 ± 0.0035
$\mathfrak{R}$	9.233 ± 0.016	-0.0126	9.2204 ± 0.0086
Q	125.46 ± 0.49	-0.509	124.951 ± 0.082
L	6.514 ± 0.023	$+0.009$	6.523 ± 0.019
a	20.466 ± 0.016	-0.011	20.455 ± 0.013
θ	$497^{s}.0 \pm 1^{s}.4$	$+1^{s}.01$	$498^{s}.01 \pm 0^{s}.31$
V	186347 ± 51 (miles per sec.)	-10 (miles per sec.)	186337 ± 50 (miles per sec.)
E	$0.000003005 \pm 0.000000023$	$+0.000000051$	$0.0000030561 \pm 0.0000000058$
M	0.01271 ± 0.00031	-0.000375	0.012335 ± 0.000036
ϵ	0.003375 ± 0.000046	-0.000044	0.003331 ± 0.000032

Not the least important part of the memoir is a series of remarks on the direction which future investigations should take to improve the system of constants as rapidly as possible. A study of the factors for the probable errors in the course of the work shows clearly that the following pieces of work are eminently desirable:—

"1. The parallax of the Moon should be determined by the diurnal method, at one or more stations as near as possible to the Equator.

"2. The observatories in the northern and southern hemispheres should co-operate with each other for two or three years in systematically making meridian observations of the Moon to improve our knowledge of its parallax.

"3. Pendulum experiments should be made at a large number of stations, located partly in the neighbourhood of the Equator, and partly as near as possible to the Poles. Experiments in middle latitudes are also desirable but somewhat less necessary.

"4. New determinations of the constants of aberration and nutation should be made by as many different methods as possible.

"5. The meridian observations of the Sun, accumulated at the Greenwich and Washington Observatories during the last fifty years, should be discussed in such a way as to deduce from them the most probable coefficient of the lunar inequality of the Earth's motion.

"6. New determinations of the solar parallax should be made by observing *Mars* during its opposition in 1892, and also

by observing such asteroids as may come into favourable positions for that purpose.

" 7. The measurement of some of the great arcs included in the scheme of the U.S. Coast and Geodetic Survey should be completed as soon as possible."

The Solar Parallax.

Since the last Report our Associate Prof. Auwers has published in the *Astronomische Nachrichten*, No. 3,066, the value of this constant from the heliometric observations made by the German expeditions in 1874 and 1882. Taken, as these were, on a uniform system by trained observers, and with instruments as nearly identical as possible, there can be no doubt that they deserve great weight.

Each single measure of the distance or reading between two limbs admits of the deduction of an equation of condition of the form—

$$n + \frac{s}{1000} \mathrm{N} = a \cos da + bd\delta + cd\pi \pm c'' \pm d\mathrm{R} \pm dv \pm \gamma,$$

where s denotes a correction to the scale value for 1000″, which is personal to each observer; and the last four unknown quantities are constants (c'' for the station and the other three for the observer), which admit of elimination by suitable combinations of the observations. Every *complete determination*, consisting of sixteen readings by the same observer, allows these four constants to be determined or eliminated from the mean equation; four readings, suitably varied, constitute a quarter determination, and eight a half determination. It would, therefore, be possible to form equations containing only s and the three corrections to the right ascension, declination and parallax, by using the observations in groups of sixteen, while s is independently determined for each observer, save in the case of Löw at the Mauritius in 1874. On this account the group of sixteen observations made by Löw is eventually omitted from consideration.

Instead, however, of taking these groups, and by meaning their equations of condition eliminating the four constant errors, Prof. Auwers has preferred to determine the most probable value of these errors for each observer or station, and to substitute them in the individual equations, in order that these may be reduced to means for groups by the use of the weights. Seventy-six quarter determinations were thus made for the transit of 1874 and 108 for that of 1882, and these are obtained as equations, each of the value of one, from complete determination. For the transit of 1874:—

6 at Tschifu.	6 at Auckland.
4 at Kerguelen I.	3 (including Löw's) at Mauritius.

Also for 1882—

6 at Hartford.	7 at Bahia Blanca.
3 at Aiken.	9 at Punta Arenas.

In each of these equations is now included a term for the effect of a small residual correction due to the observer, and in those for 1874 one depending on a residual error of longitude.

These equations of condition are then treated as of equal weight, and there result the following corrections, in which the effects of the longitude corrections in 1874 are shown to be insensible, and those of the observers' scales assumed to be so. $\Delta\alpha$ and $\Delta\delta$ refer to Leverrier's tables:—

	1874 Dec. 8. m. e.	1882 Dec. 6.
$\Delta\alpha =$	$+4''\cdot65 \pm 0''\cdot284$	$+9''\cdot11 \pm 0''\cdot124$
$\Delta\delta =$	$+2\cdot31 \pm 0\cdot097$	$+1\cdot99 \pm 0\cdot064$
$\pi =$	$8\cdot877 \pm 0\cdot043$	$8\cdot879 \pm 0\cdot037$.

The mean errors above depend on a determination of the mean error of a single measure derived from observations of the Sun's diameter at 45° ZD, on the hypothesis that closing and opening measures are liable to equal errors. A discussion, however, shows, as certainly as unexpectedly, that fifteen out of the seventeen observers make the last observations more certainly, and in the two outstanding cases the determination of the mean error is unsatisfactory. Then, though the assumed mean errors in the two series are nearly the same, a close examination of the residuals shows that they are not similar. This shows that there must have been departures in the same direction from the normal state, which lasted some time, and which, it is considered, can only be ascribed to a real deflection of the rays which reach the eye; such deflections would only occur when the zenith distance is great, and it is just in such cases, or when the observations are taken through breaks in the clouds, that these peculiarities occur. They do not affect the observations for 1882, but those of 1874 require an increase of probable error on these accounts. Moreover, though the scale values in 1882 are satisfactorily determined, so that their probable error cannot affect the parallax in the third decimal place, it is otherwise in 1874, where an increase is wanted; the probable error of π, corrected for all these causes, is $\pm 0''\cdot062$ for 1874.

The high value of the parallax determined from these observations has led to a re-examination. There is a doubt which of two chronometers was used at the Mauritius (which was the station where one of the three full determinations had been rejected for doubts about the scale); the remaining two were by the same observer, and one seemed to have considerable error which can be explained either by the low altitude or a

wrong assumption as to the chronometer used. The last explanation would lead to an increase of the parallax by 0″·007.

Prof. Auwers then shows that the rejection entirely of the Mauritius observations, and also of those in China by one of the observers, would only decrease the parallax by 0″·002.

Finally the deduced corrections for $d\alpha$, $d\delta$, $d\pi$ were substituted in the equations for each single reading, a process which led to the rejection of two observations whose discordance had escaped notice, and to the confirmation of a suspected error of the time in another, which was now corrected, and the corrections to the assumed data having now been determined, they appear—

	1874 Dec. 8.	1882 Dec. 6.
$\Delta\alpha =$	$+4''\cdot69$	$+9''\cdot13$
$\Delta\delta =$	$+2''\cdot30$	$+1''\cdot99$
	m. e.	m. e.
$\pi =$	$8''\cdot873 \pm 0''\cdot062$	$8''\cdot883 \pm 0''\cdot037$

and the mean value—

$\pi = 8''\cdot880$ with a mean error $\pm 0''\cdot032$ or probable error $\pm 0''\cdot022$.

The Diameter of the Sun.

The heliometers used by the German expeditions for determining the Solar Parallax were employed before despatch and after their return home, as well as at the selected stations, for measuring diameters of the Sun. The result is about 2,800 diameters, measured in various proportions with five instruments, each being the result of four readings of the scale.

These measures (*Ast. Nach.*, No. 3,068) have been arranged in groups, the observations for each heliometer subdivided for each observer and place (which is of course synonymous with time) of observation. The groups are separately weighted; first provisionally, when thirty measures on ten separate days are considered to be so independent of all but constant errors that they may have a maximum weight 10, subject to a reduction on account of uncertainty of scale determination; and then a second set of weights is given, which serve to combine the observations of one observer only.

Of the earlier observations some were made without the screens over the object-glasses, and this circumstance, as well as the fact that the screens in the last series were denser than those in the first, gives some idea as to the residual effects of refraction. The first mean results are—

1st series	Without screen	$1919''\cdot30$ at mean distance.
	With „	$1919''\cdot32$
2nd series	„ „	$1919''\cdot32$.

Nevertheless, Prof. Auwers considers that heliometer D seems to give a smaller image than A, B, and C, which agree ; and, moreover, that the screening of the object-glass in this instrument reduces the image. He therefore proceeds to find instrumental errors for the five instruments, though it is confessedly not easy to do this very satisfactorily. Those found vary from $-0''{\cdot}20$ for heliometer B to $+0''{\cdot}18$ for heliometer D.

Having now applied these, he proceeds to collect the results for each observer and take the means, using the appropriate weights, and to arrange them in order of magnitude. The results of the twenty-nine observers now clearly show a personality in observing, the greatest value being nearly $2''{\cdot}0$ above the least. Weights are roughly assigned, and the resulting mean diameter of the Sun is $1919''{\cdot}26$.

Setting aside now provisionally those values which differ by more than half a second from the mean, there remain twenty whose mean is $1919''{\cdot}32$, and this value makes the greatest departures either way nearly equal. Of the nine reserved results three are very weak, and the remaining six are by observers who have shown a change of habit—suddenly in the case of three, and gradually in the others. It would, perhaps, be best to take the mean of the twenty good observers as $1919''{\cdot}32 \pm 0''{\cdot}07$; but, in order to get rid as far as may be of personality, it is preferred to take the greatest possible number of observers, and the final result offered is $1919''{\cdot}26 \pm 0''{\cdot}10$.

Some of these observations were made in the direction of the solar axis and equator, others in position-angles, 0°, 30°, 45°, 60°, and at right angles to these, and, being made at varying times of the year, they are practically more or less over the whole circumference. From the nineteen sets made in the equator and plane perpendicular to it is deduced an excess of the polar axis of $0''{\cdot}026$. Again, from the twenty-seven other sets is deduced an excess of $0''{\cdot}053$, giving a general mean of $0''{\cdot}032$. To this Prof. Auwers assigns a mean error of $\pm 0''{\cdot}023$, which, of course, shows that the observations do not suffice to determine any difference.

Prof. Auwers remarks that if this value of the polar diameter be in error it must be too large ; still more, then, must those used in the ephemerides be so, and he suggests that his value should be used as more accurate. There is probably no determination of this Constant in existence which depends on so many observations by various observers with five different, though similar, instruments.

The Diameter of Venus.

During the transits of *Venus* in 1874 and 1882 the opportunity was taken to make measures of *Venus* on the Sun with the heliometer. Seventeen complete determinations were obtained in varying position-angles, but Prof. Auwers (*Ast. Nach.*, No. 3,068)

considers that these show no evidence of a departure from circular form, while his observations at Luxor in 1875 prove that there is none. These observations, then, give eleven determinations by different observers, to which may be added a twelfth at Luxor.

An examination shows that the personality of observation is very similar to that in the case of the Sun. Applying, then, the personal and instrumental errors deduced from the far more numerous solar observations, and excluding the determinations of three observers, which are considered anomalous, the value from the remaining nine is $63''{\cdot}544$, at a distance whose log is 9·422261.

Every four measures of the distance between the limbs of the Sun and *Venus* admit of a value of the diameter of *Venus* being deduced from them. This has been done, and the resulting value from seventeen observers is $63''{\cdot}75$ for the same distance; but it is considered that this is affected by a residual error similar to personality, and should not be mixed with the definite result before given.

The diameter at distance 1 is deduced as $16''{\cdot}80$. The difference between this and the value obtained off the Sun by three observers at Punta Arenas is ascribed to the effect of the atmosphere of *Venus*, and the final value of the diameter of the body of *Venus* at distance 1 is $16''{\cdot}80$, or $16''{\cdot}87$, if Auwers' observations of 1875 have applied to them a correction which he experimentally determined.

The Rotation of Venus.

In the Report of the Council for February 1891 an account was given of the interesting and important researches of Schiaparelli on the rotation of the planet *Venus*. He arrived at the conclusion that the rotation was very slow, and that the period was probably the same as that of her revolution round the Sun. The diurnal changes noticed by previous observers, which led to the adoption of 23^h to 24^h for the period of rotation, must be regarded as due to the circumstances of observation, and not to a real change in aspect of the planet. M. Niesten, of the Brussels Observatory, has since challenged these assertions and insisted on the reality of the diurnal changes, which he had ample opportunity of watching while constructing, in conjunction with M. Stuyvaert, a remarkably fine series of drawings of *Venus* in the years 1877–1890. The drawings themselves, taken alone, would appear to allow of either a rapid or a slow rotation. Even the point raised by M. Terby, to whom the memoir was referred for criticism, and whose somewhat hostile criticism is printed at length with M. Niesten's memoir, is not very conclusive. M. Terby points out that two drawings of the planet on July 14, 1881, by M. Niesten, and on September 11, 1884, by

M. Stuyvaert, are almost identical; but that the short rotation period of De Vico would require the phases to differ on these occasions by 180°, while Schiaparelli's period would make them the same. It must be remarked, however, that a great number of rotations would have meanwhile elapsed on De Vico's hypothesis; and, if this wonderful pair of drawings be accepted as giving correction to the period, this correction would amount to little more than a minute of time; though it might still not be possible to reconcile the intermediate drawings. But M. Niesten insists on the short rotation period of 23^h chiefly because he and M. Stuyvaert believe they have seen rapid displacements, relatively to the terminator, of both bright and dark spots. And it is probably to the reality of such apparent motions as these that the attention of the best observers must be directed in the future, with a view to settling this most important question.

Dr. L. Struve's Determination of the Moon's Semi-diameter from Occultations observed during the Total Lunar Eclipse of October 4, 1884.

In response to Dr. Döllen's appeal for co-operation among astronomers in observing occultations during the total eclipse of October 4, 1884, observations were received at Dorpat of 239 immersions and 175 emersions of fifty-six stars at forty-two places. At the eclipse of January 28, 1888, with better weather conditions, the number was more than doubled, but, as the exact places of the stars there observed are not yet determined, Dr. Struve confines his attention to the results of 1884, with which he hopes shortly to combine those for 1888.

For a first approximation Dr. Struve assumes k (the ratio of the Moon's radius to the Earth's equatorial radius) 0·2725, and for the Moon's mean parallax $57'2''{\cdot}27$. The geocentric places of the Moon are taken from the American Ephemeris, and therefore include Newcomb's corrections to Hansen's tables. Having first rejected all doubtful observations, he obtains 349 equations of the type

$$\Delta r + b\Delta\alpha + c\Delta\delta + d\Delta\pi = n;$$

where Δr, $\Delta\alpha$, $\Delta\delta$, and $\Delta\pi$ represent respectively corrections to the assumed radius, geocentric R.A., declination and parallax of the Moon. From these he seeks to determine the values of the unknowns by the method of least squares. Upon considering the weights he finds that they vary between narrow limits, and as in any case these limits must rest upon assumptions, he has decided to give all the equations equal weight. Thus he derives four normal equations. The correction to the assumed parallax obtained by direct solution from these is affected with

such a large probable error that Dr. Struve gives his final results in terms of $\Delta\pi$, pending the determination of π from the reduction of the 1888 eclipse observations. These results are—

$$\Delta r = +0''.334 - 0''.281\ \Delta\pi \pm 0''.073$$
$$\Delta a = -0^{s}.005 - 0^{s}.143\ \Delta\pi \pm 0^{s}.107$$
$$\Delta\delta = -0''.204 + 0''.711\ \Delta\pi \pm 0''.119$$

and from the above value of Δr

$$\Delta k = +0.000098 - 0.000082\ \Delta\pi \pm 0.000021;$$

whence

$$r = 15'\ 32''.85 - 0''.281\ \Delta\pi \pm 0''.07$$
$$k = 0.272598 - 0.000082\ \Delta\pi \pm 0.000021;$$

which must be regarded as very close approximations.

For the P.E. of a single observation he obtains the unexpectedly large value $\pm 1''.34$.

As regards observations at individual stations, the discordances show traces of systematic deviation in three instances only.

Finally, upon searching for indications of ellipticity, Dr. Struve finds that there is no systematic deviation of the form of the disc from a circle, a result fully in accordance with heliometer measures. A. E.

Herr Hartmann's Determination of the Increase of the Earth's Shadow during Lunar Eclipses.

Dr. Hartmann has investigated the amount by which the Earth's atmosphere increases the diameter of the section of the shadow during a lunar eclipse, and published his results in a paper with the title 'Die Vergrösserung des Erdschattens bei Mondfinsternissen' (*Abhandlungen der math. phys. Classe der K. Sächsischen Ges. d. Wissenschaften*, vol. xvii., Leipzig, 1891). Since the time of Tobias Mayer this increase has, in computations for some of the astronomical ephemerides, been assumed $= \frac{1}{60}$, although nothing is known as to the manner in which this quantity was determined. Several attempts have been made to find a correct value of the co-efficient, but hitherto only the observed duration of the eclipse of each lunar spot has been made use of, so that a great number of observations of only immersion or emersion had to be discarded. Dr. Hartmann has preferred to deduce from every single observation of the contact of the shadow with well-defined lunar formations the corresponding increase of the diameter of the shadow. In order to be sure that the unavoidable uncertainty

of the results of the observations is not increased by the use of approximate formulæ, the author of the memoir before us first discusses the formulæ required for the investigation, and applies them to the reduction of all the observations of lunar eclipses since 1800, those anterior to this date being too uncertain owing to instrumental deficiencies. As the personal bias of the observer must introduce a considerable uncertainty in the observation of the indistinct limit of the shadow, only such eclipses were used which had been observed independently by several observers. There were thirty eclipses of this class, of which two, however, were excluded after the completion of the investigation, as the materials were insufficient. Many erroneous identifications of lunar formations were detected and rectified. The places of the Sun and Moon were directly computed for each eclipse from Leverrier's and Hansen's Tables respectively for two epochs, which for total eclipses were taken about the mean of the observed times of immersions and of emersions respectively, as the data given in the ephemerides—viz. the places for the time of opposition with the hourly variation of both co-ordinates, were insufficient. The result of a most thorough discussion of 2,920 observations is, that the increase of the semi-diameter of the shadow at mean lunar parallax is $= 48''{\cdot}62$. Throughout the investigation it was found that the immersions gave greater values for the increase than the emersions, as if the observers were inclined to anticipate the moment of contact with the shadow, while the shadow seems to decrease in size towards the middle of the eclipse and to increase after it. These and other phenomena, among which may also be mentioned the rule that total eclipses give a smaller value of the increase than partial ones, must be left for examination by the aid of photography. The final result of $48''{\cdot}62$ (to which corresponds a coefficient of increase $= \frac{1}{50{\cdot}79}$), can, however, in any case hardly be changed more than $2''$ or $3''$ by the use of new observations (though experienced observers may be able to see about $3''$ further into the shadow), and it seems, therefore, desirable that the use of Tobias Mayer's value of $\frac{1}{60}$ should be abandoned for that of $\frac{1}{50}$.

J. L. E. D.

Lunar Radiant Heat.

The fourth volume (series 2) of the *Scientific Transactions of the Royal Dublin Society* contains a memoir on the measures of the Moon's radiant heat as made by Dr. Boeddicker at Birr Castle Observatory during the total eclipse of January 28, 1888, with an introduction by the Earl of Rosse. In this introduction Lord Rosse gives a brief outline of his earlier experiments in the measurement of lunar radiant heat,

touching on the great difficulties which encompassed the work, and referring to the chief inferences to be drawn from his results—viz., that the Moon's heat contains a much larger proportion of rays of low refrangibility than the Sun's, and that the maximum of heat radiated from the Moon falls, if anything, before rather than after the time of full. This last result suggested the advisability of trying whether during a total lunar eclipse the minimum of heat would fall before or after mid-totality. Attempts were accordingly made during the eclipses of 1872 and 1884, and on the latter occasion Dr. Boeddicker's observations appeared to show that the minimum of heat fell later than the minimum of light, and that whilst the diminution of heat proceeded faster than the diminution of light, its recovery was much slower. The eclipse of January 28, 1888, proved much more favourable than the previous eclipses had been, the sky being quite clear, and Dr. Boeddicker was able to obtain a very satisfactory series of observations, which are given in detail in the present memoir, together with the deduced theoretical curves for both this eclipse and that of 1884. The results obtained in 1884 were fully confirmed, the radiation falling considerably before the commencement of the eclipse, and "not returning to its standard value until 1 hour 40 minutes after the last contact with the penumbra." Dr. Boeddicker considers it established, after making every reasonable allowance for the uncertainty and difficulty of the research, that the decrease of heat had begun quite three minutes before the first contact with the penumbra, a conclusion which would imply that the Earth possessed an atmosphere capable of exercising a distinct heat-absorption at a height of 190 miles.

The Distribution of the Moon's Heat.

A memoir, bearing a very interesting relation to that of Dr. Boeddicker's, has been published by the Utrecht Society of Arts and Sciences, it being the essay which obtained the prize offered by that body for the determination of the heat given by the Moon in its different phases. One of the principal subjects pointed out by Dr. Boeddicker as requiring systematic observation was that of the varying radiation of different parts of the lunar surface, and this is one of the chief points to which Mr. Frank W. Very, the author of the memoir in question, has given attention.

Mr. Very's observations were made with a Langley's bolometer, together with a sensitive galvanometer. An image of the Moon about 1·2 inch in diameter was thrown upon a white card, upon which the details of the surface could be readily distinguished by means of a concave silver-on-glass reflector. A circular hole in this card, of an area a little more

than $\frac{1}{30}$ of the apparent disc, allowed the sensitive surface of the bolometer to be exposed. The method of observation consisted of a reading from the Moon taken between two readings from a blackened copper screen, containing water at a known temperature, which could be readily interposed in the path of the light at the observer's will. Comparisons were also made on every evening between the radiation from the screen and from the sky.

Bad and indifferent observations were rejected, and those only of the eight most favourable nights were retained, the dates ranging from January 12 to April 15, 1889. The results are presented in a series of charts, and in tables which exhibit the general effect at a glance.

Briefly, these results may be summarised as follows:—The maximum for light is much more pronounced than that for heat, so that the visible rays form a much larger proportion of the total radiation at the full than at the partial phase. Next, the heat areas are eccentric, having their greatest extension towards the west; the diminution of the heat in the third quarter of the lunation is slower than its increase in the second. And, lastly, there is a fair agreement between Mr. Very's results and those of Lord Rosse, although so differently obtained. Thus the result Dr. Copeland obtained in 1870, that the greatest heat was attained before the full, is confirmed by the present series of observations.

Mr. Very's researches open up a new field, as previous investigations have dealt with the radiation of the Moon as a whole, whereas his method deals with that from numerous small portions of its disc under various conditions of phase, thus affording much additional information of a kind entirely new.

The Motion of Hyperion.

The attempts to get forward in solving the very interesting problem offered by the motion of *Hyperion* have been much hampered by the uncertainty and insufficiency of the data upon which they have to be founded. The deduction of these data from the observations cannot be properly effected without some approximate knowledge of the more telling inequalities of the motion, and, though the general form of these inequalities has been known since 1884, the question of their values in the real orbit has yet to be answered. It is therefore satisfactory to learn from a paper of Dr. Hermann Struve, published in No. 3,060 of the *Astronomische Nachrichten*, that a preliminary discussion of some of the observations of *Hyperion*, which he has been enabled to make during the last five apparitions of *Saturn*, 1887–91, has allowed him to deduce approximately the coefficient and period of the chief inequality or libration of the mean longi-

tude, and thus to account for a great portion of the apparent irregularities of the mean motion which the observations have shown. It is sufficient to know that the amplitude of the deduced libration is 9°, and the period 641 days, in order to understand that it must be duly allowed for in the deductions of osculating elements of the orbit, though the observations may not extend over more than a short period. The step forward thus gained will facilitate further steps, and though progress in the solution of the problem may be slow, there is good hope that it will be steady. A. M.

The Star Catalogue of the Paris Observatory.

The second instalment of this great work has recently been published—*i.e.*, that portion of it which contains the places of stars from 6^h to 12^h of R.A. The first portion of the Catalogue appeared in 1887, and the part now published is strictly a continuation of it. The Paris Catalogue is in reality three catalogues—viz., the observations made from 1837–53, and reduced to 1845·0; those made from 1854–67, and reduced to 1860·0; and those made from 1868–81, and reduced to 1875·0. The stars are arranged in order of their R.A. at the Epoch 1875·0. The programme which was carried out for so many years at Paris included the re-observation of as many of Lalande's stars as possible. The present volume extends to No. 14,783 of the Catalogue, corresponding to No. 22,725 of Lalande's Catalogue (Baily's). The Catalogue has been prepared for publication by M. Gaillot, with the assistance of M. Bossert. The latter has also prepared a very valuable Memoir on the proper motions of the stars whose places are given in the Catalogue, deduced from a comparison of the Paris places with any others that may be available. Every effort appears to have been made for the detection and correction of errors in the work, and the Catalogue when completed will doubtless be one of the most valuable publications of its kind.

Second Munich Catalogue of 13,200 *Stars for the Epoch* 1880·0.

This is a catalogue of faint stars (7-10 mag.) observed with the meridian circle of the Munich Observatory during the years 1884–88. The stars observed are chiefly those for which there was but a single observation in the Catalogue deduced from Lamont's zones mentioned in last year's Report, or the positions of which were for one reason or another doubtful. So that the present Catalogue is to a certain extent supplementary to the First Munich Catalogue, but contains the places of a large

number of stars deduced from recent observations, which will be useful to working astronomers in a variety of ways. The positions depend on Auwers' Fundamental Catalogue, the apparent places of the standard stars having been taken from the ephemeris published in the *Berliner Jahrbuch* for the different years. The stars whose places are given in the Catalogue are situated within about 25° of the Equator both north and south. The probable error of an observation is found to be $\pm 0^{s}.081$ for a transit observed over four threads and for a mean declination of 10°, and $\pm 0''.85$ for a declination when the circle is read by two microscopes.

Professor Seeliger, the Director of the Munich Observatory, under whose direction this Catalogue was reduced and prepared for publication by Dr. Bauschinger, is doing good work at the observatory, both in the series of observations which are being carried out there and also in the prompt publication of the results, so as to render them available to astronomers generally.

Pulkowa Catalogue of 5,634 *Stars for the Epoch* 1875·0.

This Catalogue is deduced from observations made with the Pulkowa meridian-circle during the years 1874–80. The places of the stars have been reduced and the Catalogue prepared for publication by Herr Romberg.

The stars whose positions are given in the Catalogue are of various classes—many double stars from the lists of W. and O. Struve, stars with large proper motions, stars used for longitude and latitude determinations, stars used for comparison with nebulæ, &c. The total number of observations exceeds 32,000. The positions of the fundamental stars are included in the Catalogue, and a comparison of their places with the positions of the adopted standard Catalogue is given for the determination of systematic error. The Zero-point for the declinations was originally determined from observations of the collimators, but from 1878 onwards the adopted positions of the fundamental stars were used for this purpose.

The probable error of an observation is found to be—

For a fundamental star	$\epsilon_\alpha \cos\delta = \pm 0^{s}.036$,	$\epsilon_\delta = \pm 0''.34$;
„ an ordinary star	„ $\pm 0^{s}.038$,	„ $\pm 0''.34$;
„ a star of mag. 7–10	„ $\pm 0^{s}.051$,	„ $\pm 0''.40$.

A comparison of the star places of this Catalogue is given with (amongst others) the Greenwich Ten-year Catalogue for 1880. In the mean the difference of R.A. at the Equator $= +0^{s}.024$ (Pulkowa—Greenwich); there is a very close agreement in declination between the two Catalogues; that in R.A.

is, however, not so good, and exhibits a considerable range of differences depending on R.A.

The Catalogue appears to have been prepared with the care and attention to detail which characterise the work of the Pulkowa Observatory, and will doubtless prove of great value to practical astronomers.

New Edition of Oeltzen's Catalogue of Argelander's Southern Zones.

Professor Weiss has recently published a work that will doubtless prove of great utility to the practical astronomer—viz., a new edition of Oeltzen's Catalogue of Argelander's Zones, extending from 15° to 31° of south declination. The places of the stars situated to the north of 23° south declination have been compared with those given in Schönfeld's *Durchmusterung*, whilst those situated to the south of that limit have been compared with Gould's Cordoba General Catalogue and Cordoba Zones, as well as, in some cases, with the Washington Zone Catalogues, and other Catalogues which furnish positions of stars in that region of the heavens.

In this way a large number of errors in Oeltzen's Catalogue have been found, and Professor Weiss is encouraged to hope that all the errors of any considerable magnitude have been detected and corrected in this edition.

The total number of stars whose places are given in Professor Weiss's Catalogue is 18,276; they are reduced to the epoch 1850·0, and the amount of precession in R.A. and declination to bring the positions up to 1875·0 is also given. In the appendices some interesting information is furnished as to the detection of different classes of errors during the progress of the work, as to the proper motions of a considerable number of the stars, and as to the estimation of magnitudes of variable stars which occur in the Catalogue.

The Photographic Chart of the Heavens.

The second meeting of the Permanent Committee, appointed by the Astrophotographic Congress of 1887, was held at the Paris Observatory on March 31, 1891, and following days.

The following members of the Committee were present:—MM. Baillaud, Bakhuyzen, Beuf, Christie, Denza, Donner, Gill, Paul Henry, Prosper Henry, Janssen, Kapteyn, Lœwy, Mouchez, Pujazon, Rayet, Ricco, Tacchini, and Trépied. The following astronomers were also present by invitation:—MM. Abney, Andoyer, Belopolsky, Bouquet de la Grye, Cornu, Knobel, Gautier, Maturana, Plummer, Scheiner, Tisserand, and Wolf.

Admiral Mouchez gave an address at the opening meeting

recounting the progress that had been made by the various participating observatories since the last meeting of the Committee in September, 1889, and indicating the principal points to which the attention of the Committee would have to be directed.

Drs. Gill and Bakhuyzen were elected Vice-Presidents, and the representatives of each observatory were invited to state how far the photographic installation was complete and to exhibit specimens of the negatives already taken. A small committee was appointed to report upon these exhibits, who found among them a great similarity both as regards the appearance of the stars at the centre and at the edges of the plates; and all admirably suited for promoting the formation of a photographic chart of the heavens.

The more important subjects which occupied the Committee will be gathered by recording the resolutions adopted on each. These resolutions are either important in themselves, or important as effecting a change in the programme arranged at previous meetings.

(*a*) The orientation of the plates taken at a declination greater than 65° will be arranged for the equinox of 1900; for stars of a less declination the parallel will be referred to the apparent equinox.

(*b*) The work undertaken by the Congress of 1887 necessitates two series of negatives, made with different exposures. The Committee, while urging the utmost activity in the production of the plates of shorter exposure, recommends the observers to occupy themselves on those nights when the sky is at its best in the production of the negatives of longer exposure destined for the chart.

(*c*) The negatives from which the catalogue is to be formed shall exhibit two exposures: one showing feebly the images of stars of the eleventh magnitude, the other, separated by a distance of approximately the fifth of a millimetre, twice that exposure.

(*d*) The series of negatives destined to form the chart shall be taken in such a manner that an *even* degree of declination shall be in the centre of the plate. This series shall depend upon a single exposure. Observers may be required for the second series, that in which the degree of declination is *odd*, to take three exposures at the angular points of a small equilateral triangle.

(*e*) The following distribution of the zones among the various observatories was definitely accepted in place of that published in *Monthly Notices*, vol. l. p. 246.

North.			South.		
Greenwich	+90°	+65°	San Fernando	−3°	−9°
Rome	+64	+55	Tacubaya	−10	−16
Catania	+54	+47	Santiago	−17	−23
Helsingfors	+46	+40	La Plata	−24	−31
Potsdam	+39	+32	Rio de Janeiro	−32	−40
Oxford	+31	+25	Cape of Good Hope	−41	−51
Paris	+24	+18	Sydney	−52	−64
Bordeaux	+17	+11	Melbourne	−65	−90
Toulouse	+10	+ 5			
Algiers	+ 4	− 2			

The political condition of some of the States of South America has rendered uncertain the amount of assistance their respective Governments will be able to accord the scheme.

With the view of preserving and continuing Argelander's scale of magnitudes below the ninth, a sub-committee was formed to select and distribute among the participating observatories metallic screens of fine gauze and of identical structure. It was hoped that when such a screen was placed in front of the photographic object-glass, practically $\frac{5}{6}$ of the incident light would be stopped, and in this manner the appearance and light of a ninth-magnitude star would be reduced to an eleventh, and thus enable observers to determine the proper time of exposure for securing the impression of an eleventh-magnitude star on Argelander's scale. Further, it was proposed that the Paris observers having determined this necessary length of exposure (t), the fraction $\frac{40}{t}$ (in minutes of time) should be the factor for multiplying the length of exposure found necessary to obtain a satisfactory impression of stars of the eleventh magnitude, in order to obtain the proper duration of exposure for the chart plates.

A majority of the sub-committee has, however, found the proposal ineffective in practice, and has recommended its discontinuance; but to ensure the desirable uniformity of magnitude on the Catalogue plates, Professor Pritchard has, with the approval of the President of the Committee, circulated among the various observatories photographs of typical areas on the sky, on which are marked the magnitudes of a certain number of stars on Argelander's scale, determined photometrically at Oxford.

A sub-committee was likewise appointed to report on the method of reproducing the photographs to form the chart. The members, while leaving to each astronomer the choice of details in the method of procedure, recommend that the reproductions shall be effected by photogravure in such a manner as to exhibit black images on a white ground, without the interposition of a

photographic positive. The original negative will be enlarged twice, so that the space between two lines of the *réseau* will be 10 millimetres.

The *Comité International Permanent* has issued a sixth "fascicule" treating of subjects interesting to those engaged in the international chart. The subject of magnitude has, in this "fascicule," received much attention from several experts, and the subject demands still further inquiries. Dr. Scheiner in the *Astronomische Nachrichten*, Professor Pritchard in the *Comptes Rendus*, and the Astronomer Royal in the *Monthly Notices*, have all contributed to the literature of this subject.

Anticipating the appearance of another "Bulletin," M. Loewy has published the details of a scheme having for its object the diminution of the number of fiducial stars required for the reduction of the Catalogue plates by combining the measurements made on contiguous negatives. The Committee appointed to report on the observation and collection of the necessary data recommended that the positions on each plate should be made to depend on the meridian observations of six stars suitably situated on each plate. M. Loewy computes that the full development of such a plan would require the accurate observation of some 60,000 or 70,000 stars which at present do not exist in any catalogue, and these stars would probably be required to be observed twice at two observatories. M. Loewy proposes to make use of the fact that, owing to the plan by which the plates of the second series will overlap those of the first, any star on a plate will be found on one of the four plates which cover the first, so that by a triangulation the four superposed plates can be made available for the reduction of the first. By continuing the process, all the known stars in a space of 36 square degrees can be used to determine the positions of the stars measured on the first plate, and even further combinations, M. Loewy suggests, can be made. In this way a sufficient number of stars, whose places have been accurately determined already, exist for the discussion of the Catalogue plates.

Prominence Photography.

Mr. G. E. Hale, Director of the Kenwood Physical Observatory, Chicago, has made the work of photographing the forms and spectra of prominences the subject of his special attention. His earlier attempts were made upon the C line, some ingenious arrangements of moving slits being devised to give photographs of the complete prominence. Latterly he has, however, turned his attention to the H and K lines, and here a much greater measure of success has attended his efforts.

The spectroscope employed is a large one, and is mounted on the 12·2-inch equatoreal of the Kenwood Observatory. It consists of a 4-inch Rowland grating, ruled with 14,438 lines to the

inch, together with a collimator and telescope, rigidly fixed at an angle of 25° to each other, and each having an aperture of $3\frac{1}{4}$ inches and a focal length of $42\frac{1}{2}$ inches. The spectrum of the fourth order is generally employed.

Early last April Mr. Hale secured the first photograph of the spectrum of a prominence obtained without an eclipse. This showed two very strong bright lines nearly at the centres of the dark solar bands H and K. The same lines were photographed on subsequent occasions, but it was not until June 23 that any new lines were discovered. On this occasion four lines were obtained in the ultra-violet—a number since increased to six. Of these six, five lines belong unmistakably to the series of hydrogen lines discovered by Dr. Huggins in the ultra-violet of the spectra of Sirian stars. The sixth line forms a close double with one of these hydrogen lines (a), but its origin has not yet been accounted for. It would seem from its appearance not to be due to hydrogen, though so frequently in close connection with one of the series. The a line in stellar spectra shows no signs of duplicity, so that this companion line is probably of a different origin.

Professor Young, who has also obtained a considerable number of photographs of the ultra-violet spectrum of the chromosphere, and has, like Mr. Hale, constantly obtained the reversal of the H and K lines, and succeeded in obtaining the first five members of the Huggins series, has failed to detect this companion line to a, a result the more curious since nearly all Mr. Hale's plates which show a show it as double.

Mr. Hale's conclusion that H and K are not due to hydrogen is abundantly confirmed by Professor Young, and also by M. Deslandres, who has been working in the same field at the Paris Observatory with considerable success, since the measures have shown beyond a doubt that the "companion line to H," and not H itself, is the one really due to hydrogen. Mr. Hale and M. Deslandres ascribe these two giant bands of the solar spectrum to calcium, an opinion Professor Young hesitates to accept. If the bright H and K lines are due to calcium, then it would appear from the observations of both Mr. Hale and M. Deslandres that the vapours of that metal rise higher in the solar atmosphere than do those of hydrogen.

In addition to these most noteworthy results obtained already, although this new field has only just been entered upon, both Mr. Hale and M. Deslandres have taken several photographs showing interesting examples of the displacements of chromospheric lines in solar storms. His success in obtaining the reversal of the H and K lines in the spectra of prominences has also induced Mr. Hale to attempt to photograph their forms. For this purpose these lines are especially well adapted, since the presence of the broad dark lines of the solar spectrum enables the slit to be opened wide without too great interference from the atmospheric glare. He has met with considerable

success in this work, some of the photographs showing a satisfactory amount of detail. In one instance a prominence photographed at Kenwood was being sketched by Herr Fényi at Kalocsa at the same moment of time, and drawing and photograph show a close accord. M. Deslandres has also attacked the same problem and proposed that a uniform rotation should be given to the spectroscope, the sensitive plate being at the same time made to travel across the field at the same rate. In this way a complete picture of the entire chromosphere could be readily obtained. A young Englishman also, Mr. Evershed, of Kenley, though with very small optical means, his equatoreal only having an aperture of $2\frac{3}{4}$ inches, and his collimator having a focal length of only 6 inches, has succeeded in obtaining some most creditable photographs of the prominence forms.

The Solar Spectrum at Medium and Low Altitudes.

An important study of the telluric spectrum, due to Dr. L. Becker and published in the *Transactions of the Royal Society of Edinburgh*, has appeared during the year. Its chief feature is a catalogue of 3,637 lines of the solar spectrum, the position and intensity of each of which has been observed a number of times, both with the Sun at a medium elevation and when it is low down on the horizon. To effect a work of such magnitude during such opportunities as two summers afforded would have been quite impossible but for the ingenious recording instrument which Dr. Becker devised and constructed. Its fundamental idea was the magnification of the motion of the grating to such an extent that it could be recorded on a continuous fillet of paper, so that, the viewing telescope being firmly clamped, the exact positions of the grating could be pricked off on the fillet as the lines were successively brought up to the cross-wires in the field of view. This was effected by a system of geared wheels, the first of which had an angular motion 16,800 times as large as that of the grating. The recording-wheel was also turned by this driving-wheel, and the resulting scale on the paper fillet which passed over the recording-wheel was such that the D lines were nearly 20 inches apart, and the entire spectrum mapped—from λ 6024 to F—would require a strip 314 feet long. A set of five prickers arranged across the fillet enabled the observer by using various combinations of them to make 31 different signals. Only 19 were, however, employed, of which 14 were used to indicate the degree of intensity of the lines observed.

The observations were made during the summers of 1887 and 1888, with three days in 1889, from the top of the Barmekin, a hill about 850 feet high in a commanding position about a mile and a half from Dun Echt Observatory. Lord Crawford erected a temporary observing station here and provided it with suitable accommodation for camping out, as Dr. Becker was

generally obliged, owing to the shortness of the summer nights and the distance from Dun Echt, to spend the night at the station.

His instrumental equipment consisted of an object-glass of 6 inches aperture and 7 feet focal length, used in connection with a heliostat to throw the Sun's image upon the slit of the spectroscope. The latter consisted of a Rowland grating of 14,438 lines to the inch, the ruled surface being 5·5 by 3·8 inches, with collimator and view-telescope, both of 4 inches aperture, and fixed at an angle of 25° to each other. The observations were made in the second-order spectrum, and in most cases were obtained on both sides of the normal. Their reduction was most carefully effected, some 260 standard lines being employed, adopted for the most part from Professor Rowland's essay "On the Relative Wave-lengths of the Lines of the Solar Spectrum."

The advance made by Dr. Becker upon our previous knowledge of the details of the telluric bands is very considerable. Except the band by D, popularly known as the "Rain-band," no telluric band in the portion of the spectrum examined by Dr. Becker had been resolved into lines until the appearance of M. Thollon's superb atlas, which was unpublished at the time when Dr. Becker commenced his task. And even as compared with that magnificent work, Dr. Becker has succeeded in recording a very considerable percentage of new lines, both solar and telluric—a result probably due to the superiority possessed by a first-class grating over even so powerful a train of prisms as that employed by the great French spectroscopist.

The chief results arrived at by Dr. Becker is that, with the exception of twenty-eight lines, all the telluric lines in the portion of the spectrum which he has studied are comprised in three bands situated respectively in the regions $\lambda = 6020$ to 5666, $\lambda = 5530$ to 5386, and $\lambda = 5111$ to 4981, the two last being Brewster's bands ζ and ι, and that all the darker lines are due to water-vapour. The several bands of the water-vapour lines form a very interesting series, the wave-lengths of the centres of five out of seven being very nearly in harmonic progression. The first of the three groups above mentioned would itself appear to consist of three bands, the first and last being water-bands, viz.: the "Rain-band," and Brewster's band δ, whilst a group of fainter lines, due probably to oxygen, lies between. Band δ would seem to have been ascribed to dry air by Brewster and Angström, but Dr. Becker's observations lead him to ascribe it to water, at any rate as regards its principal lines.

The catalogue contains not merely the mean intensity of the lines with both a high and low Sun, but also the details of the separate observations, 26,107 in number, for the Sun on the horizon, and 8,325 for the Sun at a medium elevation: an addition which may be very useful to later inquirers. A double chart of the spectrum, carefully prepared by Dr. Becker himself, and re-

produced by photolithography, which occupies ten plates at the end of the memoir, exhibits the spectrum as seen at moderate altitudes of the Sun, and the telluric spectrum alone when the Sun is close to the horizon.

The Draper Catalogue of Stellar Spectra.

The Report of the Council for 1888 drew attention to the important work which was then being set on foot at the Harvard College Observatory in furtherance of Mrs. Draper's desire to commemorate the memory of her late husband in the manner most worthy of one who had been so devoted and successful a worker in the new lines of research which the development of the spectroscope and of photography had opened out. For this purpose Mrs. Draper had liberally supplied Professor E. C. Pickering with instruments and funds, and now one most important item of the programme, which Professor Pickering had proposed to himself when he accepted this trust, has been brought to a successful conclusion.

The work proposed in connection with the Draper Memorial was the study of stellar spectra by means of photography, that being the particular research which had most engaged Professor Draper's attention during the last years of his life. And this divided itself into two chief branches: one the formation of a general spectroscopic catalogue, the other the more detailed study of the spectra of the brighter stars. The former work—so far, at least, as it regards the stars from the north pole down to south declination 24°—has been completed, and forms vol. xxvii. of the *Annals of the Astronomical Observatory of Harvard College*, to which it is proposed to give the convenient and appropriate name of "The Draper Catalogue."

The catalogue contains details of the spectra of 10,351 stars, deduced from the measurement of 28,266 spectra—all the stars, in fact, in the region surveyed down to about the seventh magnitude, excepting those of a reddish colour. So great an undertaking could not have been effected in so short a space of time but for three circumstances to which Professor Pickering draws attention—viz., the increased sensitiveness of photographic plates, the use of an object-glass prism instead of a spectroscope of the usual form, and the substitution of a photographic doublet for the usual objective. The advantage of this combination was that it enabled all the stars over a field 10° square to be photographed at once, and with an exposure, in the case of equatorial stars, of only about five minutes.

The instrument employed was a Voigtländer lens of 8 inches aperture and 44 inches focal length, with a prism, 8 inches square and having a refracting angle of 13°, fastened before it, the refracting edge of the prism being parallel to the Equator.

The spectrum of the star formed a line on the plate, and by altering the speed of the driving-clock any desired breadth could be given to the image of the spectrum. The spectra obtained were 0·4 inch in length by 0·04 in breadth. Three or four exposures were usually made upon each plate—a practice which seems open to serious objection, though it of course lessened the cost of the survey. Mrs. Fleming superintended the measurement of the plates and the preparation of the catalogue, being assisted throughout by a staff of ladies.

The volume contains five tables, of which the first is the actual Draper Catalogue. This contains the reference number of each star, its number in the *Durchmusterung* and in the Harvard Photometry, its place for 1900, and the number of photographs obtained of it. Then follow the type of the spectrum and its photographic magnitude, and a table of the differences between this last value and the Bonn, Argentine, and Harvard magnitudes respectively. The types of spectra upon which the classification is based are not precisely those of Secchi, or of any other previous grouping, since certain grades of difference were readily recognised in the part of the spectrum most easily photographed—viz., the violet—which escaped notice in that part which is brightest to the eye. Instead, therefore, of Secchi's four types, no fewer than 16 classes are adopted, which are distinguished by letters of the alphabet.

The classification is, in brief, as follows:—Classes A to D correspond to Secchi's type I. These show Dr. Huggins's hydrogen series of lines as their chief feature. When these lines and the K line alone are seen the star is of class A; if other lines are present, of class B. A doubling of the lines G and *h* denotes class C, and the presence of bright lines, class D. Letters E to L correspond to Secchi's second type, the letter E being used when only the lines F, H, and K are seen, the letter F if the hydrogen lines are visible, and the letter G if other lines are seen as well. Different changes in the intensity of the continuous spectrum are grouped under the letters H, I, K, and L. The third type is indicated by the letter M, the fourth by N, bright-line stars by O, planetary nebulæ by P, and stars not comprised under any of the previous heads by Q.

The "photographic magnitude" which follows the spectrum-type is an attempt to determine the brightness of stars on a new principle, for instead of the *total* light of the stars being compared, only the light of a particular wave-length, near the G line, is taken. On this plan the relative magnitude of any two stars should always be the same, whether observed directly by the eye, or by photography, or by the bolometer. It is, therefore, the inauguration of a new system of photometric comparison, which may possibly prove of great importance hereafter. In the meantime an immense amount of material for future discussion is accumulated here.

Following the catalogue proper is a second table, containing

certain details of the measurements of the spectra, in particular the "photographic magnitude" of each star as deduced from the several plates on which it appears, the intensity of the F and K lines in its spectrum, and the distance in the ultra-violet to which the hydrogen series of lines can be traced. Further details are supplied in the "Remarks," which occupy 112 pages, so that the catalogue contains much more than the mere assignment of each star to its proper type; a great amount of additional information is also given.

Other tables contain a list of the types of spectra of Bayer's stars, and of the numbers of stars observed in each hour of R.A.

The discussion of the vast mass of material here brought together is reserved for vol. xxvi. of the *Annals*. Yet several interesting results appear on the surface. The insufficiency of Secchi's types when applied to the photographs of stellar spectra, the possibility and even the necessity of a minuter classification, when the violet and the ultra-violet regions are examined, than when the spectra are viewed directly by the eye, are important conclusions. Comparisons of the Draper Catalogue with those of Vogel and von Konkoly show also that the visual type is not an unerring guide to the photographic, and *vice versâ*. A further point of interest to which Professor Pickering has drawn attention is the predominance of stars of Secchi's first type in the Milky Way, a circumstance which must be of much importance in any theory as to the nature and formation of that ring.

Strassmaier and Epping's Researches on Babylonian Astronomy.

It was in the year 1881 that Fathers Strassmaier and Epping first began their joint labours on this almost unknown branch of science, Father Strassmaier deciphering the Assyrian texts, and his colleague submitting them to mathematical analysis, thereby suggesting new readings and the meanings of unknown words. The result has been that they have established in great measure the system of the astronomy of the Babylonians, and not merely the translation of a few odd texts. The work so far accomplished—and it is still progressing—embraces the thorough understanding of their method of calculating and predicting the new Moon, the establishing of the dates of the era of the Seleucidæ in Julian style, the explanation of their lunar and planetary calendars, and the mode of prediction used therein, as also the publication of several lunar and planetary tables of observation: one of the lunar eclipses thus brought to light being, as Dr. Oppert has pointed out, one of the nine used by Ptolemy in the *Almagest*. The papers published by Fathers Strassmaier and Epping have appeared in the *Stimmen aus Maria Laach*, since 1881; as also in the *Zeitschrift für Assyriologie*, 1890, pp. 281 *et seq.*, pp. 341 *et seq.*; 1891, pp. 89

et seq., and pp. 217 *et seq.* They also published in 1889 a work entitled *Astronomisches aus Babylon, oder das Wissen der Chaldäer über den gestirnten Himmel.* The chief results so far obtained may be thus summarised:—

1. *Tables of Calculation.*—These contain a complete method of calculation for the determination of the new Moon, comprising the calculation of the time by which the last crescent visible before conjunction precedes the rising of the Sun, the determination of the new Moon, and the calculation of the interval of time between new Moon and first crescent. As an example of the method we may take the following from the columns called by Epping b, c_1, c_2, d, and e of the Table A, denoting by Roman numerals the different horizontal lines. We must first premise that they divided the day into 360° of time, as appears from these tablets, each degree being divided by 60 and 60. Suppose, then, knowing the date and instant of true new Moon for the Month I., they wanted to pass to that of II. The process may be thus represented:—II. e = I. e + II. d; while II. d = II. $b \pm$ II. c_2, or = II. $b \pm$ I. c_2 − II. c_1. Column b has its terms in A.P., common ratio 22° 30′ (of time); likewise column c_1, common ratio 6° 47′ 30″. Column b then contains the term necessary to add to twenty-nine days to pass from one conjunction to the next, after correction by c_1 and c_2, which take account of the term depending on the motion of the true Sun. It follows from these tables that they had a remarkable knowledge of the mean duration of the synodic and anomalistic months, the former differing by only half a second from Hansen's value for 1800 A.D., and the latter by one-and-a-half seconds. Another column of figures shows that they knew the mean velocity of the Moon, and consequently the sidereal month. It is not quite clear that they were able to distinguish the different kinds of years; but they had a very approximate knowledge of the maximum velocities of Sun and Moon, as also of the law of variation of the velocity of the Sun at the different epochs of the year. As a confirmation of the truth of Epping's results, we may remark in passing, that he has actually succeeded in constructing a column for one table to which an exactly corresponding column was found in another table, as also in giving the true reading for a damaged column.

2. *Chronological Results.*—The commencement of the eras of the Seleucidæ (S.E.) and of the Arsacidæ (A.E.) have been fixed with a certainty which is based upon the calculation of eclipses contained in the Lunar Calendars. The years of the Seleucidæan era were luni-solar; their months lunar, sometimes of thirty, at others of twenty-nine, days. They employed intercalary months, but according to what law is yet unknown. The year commenced with the month Nisan, which fell about the spring equinox. The five following dates have been determined by Father Epping:—

1 Nisan 188 S.E. = April 4 – 123 J.E.
„ 189 „ = March 25 – 122 „
„ 190 „ = April 12 – 121 „
„ 201 „ = „ 10 – 110 „
„ 202 „ = March 30 – 109 „

Hence the Seleucidæan era began in the year –310 of the Julian era, and that of Arsacidæ in the year –246. The civil day of the Babylonians began at sunset, and the division of the day into twenty-four hours was in use amongst them. But their astronomers, as is evident from the calculating tables, besides using a division of the day into 360 time-degrees, referred its commencement to the midnight following the beginning of the civil day.

3. *Lunar Ephemerides.*—An example may be that for the month Nisan of the year 189 S.E.:

1	20	30 tab.	13	9	na.
12	1	10 shu.	14	8	30 mi.
13	8	4 me.	26	15	mat.

Six phenomena are predicted for each month, one for the beginning, four about the middle, and one for the end of the month. Predicted—for were these indications observations, their astronomers must, unlike any others, have been blessed with fine weather at almost stated intervals every month. But, a stronger argument, there are five errors of position in the tables, which, if the indications are observations, would compel us to believe that their astronomers affirmed they saw the Moon above the horizon when it was below. The first and last phenomena predicted are the times measured in time-degrees along the equator or the ecliptic—for this point is still unsettled—during which the first crescent will remain above the horizon, and during which the last crescent will remain visible before disappearing in the Sun's rays. The other phenomena relate, two of them to settings of the full, or nearly full, Moon, one of which will precede and the other will follow sunrise; the other two to risings of the full, or nearly full, Moon under the same conditions.

These tables also contain predictions for five eclipses of the Sun and five of the Moon, with their conditions of visibility at Babylon. As an example of their correctness we may take that of the Moon predicted for the 15 Ijar 201 S.E. at 1° 1° before the rising of the Sun, of magnitude 5, and visible at Babylon. According to Epping the prediction is for the year – 110 J.E., May 23, $7^h\ 20^m$. Oppolzer's Canon gives an eclipse, magnitude 4·5, visible at Babylon for May $23^d\ 7^h\ 22^m$ of this year.

4. *Planetary Ephemerides.*—By means of these tables the authors have been able to give the Assyrian names, or ideograms,

for all the planets. For instance, the name which occurs most frequently is *gut-tu*, which Assyriologists hitherto always translated as *Jupiter*. But *gut-tu* is *Mercury*, a planet the observations of which seem to have been very important for their astronomers. Their method of fixing the positions of the planets, was by drawing a series of lines as perpendicular as possible to the ecliptic, through sets of couples of bright zodiacal stars. The time when the planet would pass such a line, and its distance above or below a bright star, are the time and place predicted and observed. They also predicted the oppositions and stationary points of the planets, as well as their heliacal risings and settings. The oppositions and heliacal risings and settings of *Sirius* are also predicted. Hence we learn the names of twenty-eight stars and a good number of constellations. The astronomical seasons are also determined on these tablets. Moreover, they knew the periodic times of the planets, and used systematic compilations of observations to predict future ephemerides.

A great deal of material still remains to be thoroughly discussed by the authors, which, we may hope, will be as fruitful in results as their past labours have led us to expect. These observations of 2,000 and more years ago, especially those of the Moon, which seem to have been made with the greatest care and exactness, may possibly prove of service in the correction of modern tables. A. L. C.

The British Astronomical Association.

The British Astronomical Association was founded during the autumn of 1890 as an association of amateur astronomers for the United Kingdom, and more especially for those who, from one circumstance or another, might be precluded from joining the Royal Astronomical Society. It thus included ladies, of whom many take an interest in the science and have contributed to its progress.

That the Association met an acknowledged want was proved by the rapidity with which the names of those desirous of joining it were sent in. By October 18, 1890, when the first general meeting was held, 283 members had already joined, and by the end of the first session 584 members had been enrolled, there being at the present time considerably over 600 members, including 30 ladies.

Although the Association was intended primarily for the United Kingdom, of the 584 members who had joined during the first session, 33 are resident in the United States or Canada, 2 in Mexico, 2 in South America, 8 in India, 19 in Australia and New Zealand, 11 at the Cape of Good Hope, and 3 in China and Japan; and most of the well-known astronomical societies are represented amongst the members of the new Association.

The great object of the Association being the organisation of amateur observers for mutual help in suitable departments of observation, a leading feature of the Association has been the establishment of sections, under the guidance of competent and experienced directors, for the observation of various classes of objects and celestial phenomena. There are now eleven sections for the observation of the Sun, Moon, planets, solar and stellar spectroscopy, variable, coloured, and double stars, comets, and meteors, as well as a photographic section.

Several of these sections, in the work of which over 100 of the members are associated, have already done good systematic work.

The *Journal* of the Association, under the able editorship of Mr. E. W. Maunder, is a model of what such a publication should be, and has contributed not a little to the success of the Association. A. C.

Telegraphic Determination of Longitudes in Mexico, Central America, the West Indies, and on the North Coast of South America, 1888–89–90.

In 1883 the Bureau of Navigation of the United States Navy commenced a systematic determination of secondary meridians by telegraphic measurements of the differences of longitude. The plan was to work from Galveston in Texas, down the Gulf of Mexico, and thence down the west coast of Central and South America to Valparaiso. In 1885 a report* of the portion of the work then accomplished was published. The difficulties to be overcome in completing the portion between Vera Cruz, on the Gulf of Mexico, and La Libertad, on the Pacific Coast of Central America, caused this to be postponed. It was, however, taken up again in 1888, and the work of the expedition forms the text of the present publication. The following is a list of longitudes and latitudes determined by this second expedition :—

	Longitude West	Latitude North
	h m s	° ′ ″
Coatzacolcos (Lighthouse)	6 1 39·11	18 8 56·3
Salina Cruz (Summit of Morro de Salinas) ...	6 20 49·07	16 9 35·9
La Libertad (Iron Wharf)	5 57 17·29	...
San Juan del Sur (Signal Station) ...	5 43 31·97	11 14 44·6
St. Nicholas Mole (Fort St. George) ...	4 53 32·45	19 49 15·1
Port Plata (Lighthouse)	4 42 45·77	19 48 50·8
Santo Domingo (Lighthouse)	4 39 31·95	18 27 53·6
Curaçao (Rif Fort Lighthouse)	4 35 45·82	12 6 20·1
La Guayra (Lighthouse near Breakwater) ...	4 27 44·37	10 36 57·4

* This was noticed in the *R.A.S. Report*, 1886, February.

The equipment of the expedition was very complete, and, at the suggestion of the hydrographer, Lieutenant Dyer, a set of instruments for magnetic observations, consisting of a magnetometer and dip circle, was included in the outfit.

The transits were of 30 inches focal length and $2\frac{1}{2}$ inches aperture. The eyepiece was at the end of the axis, so that the observer always retained the same position. On the former expedition the spider-line reticules met with so much injury in transportation that it was decided to use ruled-glass diaphragms. Seven wires were used for transits. The chronographs were of the cylinder type, light and easily adjusted. Each party also carried a Siemens polarised ink-writer, which was found exceedingly useful as a telegraph instrument, a chronograph, and a polarised relay where the feeble current demanded an extremely delicate relay. It is practically what in the recent Paris longitude work was known as 'the table.' A pier of brick and cement, 24 inches by 22, and 36 inches high, was built at each station. Longitude work was generally commenced between seven and eight in the evening, the telegraph lines being free after eight o'clock. Five or six time stars would be observed, and two or three polars, when the instrument was reversed and a similar set taken. The line-connections were made so that the chronograph at one station would register its beats on its own cylinder and on that of the distant station simultaneously. For latitude work pairs of stars were selected within 25° of the zenith, the stars of each pair not differing more than 20′, and ranging from 2^m to 15^m in R.A.

No corrections were made for personal equation. It was impracticable to exchange observers, owing to the conditions of transport. The best thing, under the circumstances, appeared to be to locate the observers alternately east and west of each other, thus diminishing, if not eliminating, the P.E. at every second station.

The method of reduction was that always employed in American longitude work. The collimation, level, and azimuth obtained in the ordinary way were used as approximate values to reduce the observations. These corrected observations, after the application of diurnal aberration, hourly rate, inequality of pivots and flexure, furnished equations of condition for the final reduction to determine the correction to assumed errors. These equations were solved by the method of least squares. The hourly rate was obtained graphically—a process well suited to this class of observation. The observations are given in detail, and at the end of each night are the resulting normal equations. In addition to giving the figures of the resulting longitudes and latitudes, large-sized charts are appended for easy identification of the sites of the piers, &c.

The unifilar magnetometer and the dip circle were set up at each station. The constants and corrections were carefully

obtained, and, as in the previous work, given in great detail. The following table shows the results :—

Locality	Date	Declination East	Dip.	Horizontal Intensity (British units)
		° ′	° ′	
Vera Cruz, Mexico	Dec. 1888	7 13	44 20	...
Coatzacoalcos, Mexico	Feb. 1889	6 53	43 3	7·2890
Salina Cruz, Mexico	Mar. 1889	6 59	40 2	7·4300
Port Plata, San Domingo	Dec. 1889	0 37	49 50	6·6667
Curaçao, W. Indies	Jan. 1890	2 28	39 13	6·9841
La Guayra, Venezuela	Feb. 1890	2 51	37 35	6·9496

The value of the work becomes naturally enhanced from the fact of being the connecting-link between the two portions previously done. T. L.

Papers read before the Society from February 1891 to January 1892.

1891.

Mar. 13. Ephemerides of the satellites of *Uranus*, 1891. A. Marth.

Ephemeris for physical observations of the Moon, 1891, Feb. 12 to May 5. A. Marth.

On the determination of double-star orbits from spectroscopic observations of the velocity in the line of sight. A. A. Rambaut.

The Companions of *Aldebaran*. S. W. Burnham.

Catalogue of 918 orbits of meteor streams, from the observations of Mr. W. F. Denning. J. Kleiber.

Mean places of comparison stars for the planets *Victoria* and *Sappho*, observed with the Cambridge transit-circle. Communicated by Professor J. C. Adams.

Observations of the satellites of *Saturn*: conjunctions with the centre of the planet, observed at Mr. E. Crossley's Observatory, Bermerside, Halifax. J. Gledhill.

Observation of the variable star S (10) *Sagittæ*. J. E. Gore.

The orbit of κ *Pegasi* (β 989). S. W. Burnham.

Measures of double stars made at Sydney Observatory in the years 1882–89. Communicated by H. C. Russell.

Comparison of the star-places of the Greenwich Ten-year Catalogue with those of the Second Melbourne General Catalogue, and with those of the Cape Catalogue for 1880. A. M. W. Downing.

Double-star measures, made at Windsor, New South Wales, 1889 and 1890. John Tebbutt.

Note on the orbit of *Juno*. A. M. W. Downing.

Ephemeris for physical observations of *Jupiter*, 1891. A. Marth.

Observations of the planet *Victoria* and comparison stars, made with the transit-circle of the Radcliffe Observatory Oxford, during the opposition of 1889. Communicated by E. J. Stone.

Notes on the preparations for the Astro-photographic Chart at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Mar. 13. Variations of latitude deduced from the observations of *Polaris*, made at Greenwich, 1851–89. Professor H. G. van de Sande Bakhuyzen.
Note on the parallax of *β Aurigæ*. Professor C. Pritchard.

Apr. 10. *Sirius*. S. W. Burnham.
Observations of phenomena of *Jupiter's* satellites, made at Windsor, New South Wales, in the year 1890. John Tebbutt.
Reduction of measures of the photographs of *Jupiter*, taken at the Lick Observatory in 1890. A. Stanley Williams.
Sur la détermination récente de la longitude Paris-Greenwich. Col. Bassot and Commandant Defforges.
On the recent determination of the longitude Paris-Greenwich; reply to Colonel Bassot and Commandant Defforges. H. H. Turner.
On the orbit of the periodic Comet 1867. I. Dr. Ludwig Becker.
Invisible double stars. S. W. Burnham.
A comparison of the north polar distances of the *Nautical Almanac* for 1880 with the Cape Catalogue, the Greenwich Ten-year Catalogue, and Boss's Standard Star places for 1880. W. G. Thackeray.
Approximate proper motions of certain Groombridge stars. W. G. Thackeray.
The perturbations of *Sappho* (80). R. Bryant.
Ephemeris for physical observations of the Moon, 1891. A. Marth.

May 8. On the character of the chief line of the nebula in *Orion*. K. D. Naegamvala.
Photograph of *Neptune* and its satellite. Isaac Roberts.
Photograph of the region of Hind's variable nebula in *Taurus*. Isaac Roberts.
Photograph of the cluster 44 M *Cancri* (the *Præsepe*). Isaac Roberts.
Further experience regarding the magnitude of stars, as obtained by photography at the Oxford University Observatory. Professor C. Pritchard.
On a new dome to be erected at the Royal Observatory, Greenwich. W. H. M. Christie.

June 12. Notes on some star photographs recently taken at the Sydney Observatory. No. 2. H. C. Russell.
The Companions to *Regulus*. S. W. Burnham.
Probable early observation of an immersion of *Titan*. Rev. S. J. Johnson.

June 12. On the transit of *Mercury*, 1891 May 9, as seen at Daba Gardens, Vizagapatam. A. V. Nursingrow.

Observations of the transit of *Mercury*, 1891 May 9. K. D. Naegamvala.

Proper motions of twenty southern stars. Dr. J. L. E. Dreyer.

A method of photographing the invisible solar prominences. G. E. Hale.

Photographs of the metallic spectra. Frank McClean.

Observations of the Moon, made at the Radcliffe Observatory, Oxford, during the year 1890, and a comparison of the results with the tabular places from Hansen's Lunar Tables. E. J. Stone.

Observations of the partial solar eclipse of 1891 June 6, made at the Radcliffe Observatory, Oxford. Communicated by E. J. Stone.

Data for computing the positions of the satellites of *Jupiter*, 1891; with tables of the inequalities. A. Marth.

Ephemeris for physical observations of the Moon, 1891. A. Marth.

Observations of the transit of *Mercury*, 1891 May 9, made at the Royal Observatory, Edinburgh. Dr. R. Copeland.

The orbit of 36 *Andromedæ* (Σ 73). T. Lewis.

Preliminary note on the change of personal equation with stellar magnitude in transits, observed with the transit-circle at the Royal Observatory, Greenwich. W. H. M. Christie.

Nov. 13. The transit of *Mercury*, 1891 May 9, observed at Sydney Observatory. Communicated by H. C. Russell.

The motion of 20 *Draconis*. S. W. Burnham.

Observations of the transit of *Mercury*, 1891 May 10. W. J. McDonnell.

Observations of the conjunction of *Venus* and *Jupiter*, 1891 April 7. John Tebbutt.

Observations of the solar eclipse of 1891 June 6, made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Observations of the planet *Jupiter* and his satellites during 1890, with the 12-inch equatoreal of the Lick Observatory. E. E. Barnard.

Note on the first satellite of *Jupiter*. E. E. Barnard.

On the phenomena of the transits of the first satellite of *Jupiter*. E. E. Barnard.

Ephemeris for physical observations of the Moon, 1891 November 9 to December 25. A. Marth.

Nov. 13. Ephemeris of the satellite of *Neptune*, 1891–92. A. Marth.

Ephemerides of the satellites of *Saturn*, 1891–92. A. Marth.

On the orbit of Spitaler's comet (vii. 1890). Lieut.-Gen. J. F. Tennant.

On the determination of azimuth by elongations of *Polaris*. H. Jacoby.

Colour changes in the markings on the surface of the planet *Jupiter*. E. E. Barnard.

Observations on the spots and markings on the planet *Jupiter*, made with the 12-inch equatoreal of the Lick Observatory. E. E. Barnard.

On the determination of a certain class of inequalities in the Moon's motion. E. W. Brown.

Measures of planetary nebulæ made with the 36-inch equatoreal of the Lick Observatory. S. W. Burnham.

Corrections and additions to the observations of *Sirius*. S. W. Burnham.

Mean areas and heliographic latitudes of Sun-spots in the year 1890; deduced from photographs taken at Greenwich, at Dehra Dûn (India), and in Mauritius. Communicated by the Astronomer Royal.

Observations of Wolf's periodical comet (*b* 1891). Communicated by the Astronomer Royal.

On new forms of levels. H. H. Turner.

On the supposed duplicity of the first satellite of *Jupiter*. A. Stanley Williams.

Double-star measures, 1888–91. W. H. Maw.

On the reduction of transit observations by the method of least squares. H. Jacoby.

Re-appearance of *Saturn's* ring. Rev. A. Freeman.

A note on some photometric experiments connected with the application of the law of limiting apertures to small object-glasses. E. J. Spitta.

Comparative photographic spectra of the Sun and the metals, series I.–II. Frank McClean.

Ephemerides of the satellites of *Saturn*, 1891–92. A. Marth.

Note on some photographs of *Jupiter*, taken with the 5-foot reflecting telescope. A. A. Common.

Note on the Lunar Theory. Professor A. Cayley.

Dec. 11. The motion of Σ 2525. S. W. Burnham.

Observations of Comet Barnard, 1891, made at Sydney Observatory. Communicated by H. C. Russell.

On the close conjunction of *Venus* and *Jupiter*, 1892 Feb. 5–6. A. Marth.

Dec. 11. Note on the Stonyhurst drawings of solar spots and faculæ. Rev. W. Sidgreaves.

Secular perturbation of the Earth's orbit by *Mars*. R. T. A. Innes.

Observations of Comet Encke, made at the Radcliffe Observatory, Oxford. Communicated by E. J. Stone.

Observations of Comet *b*, 1891 (Wolf), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

On the spectrographic method of determining the velocity of stars in the line of sight. Professor H. C. Vogel.

Note on some apparently variable nebulæ. Dr. J. L. E. Dreyer.

Note on the variability of Es-Birm. 973 = D.M. +39°, 4208. Rev. T. E. Espin.

On the verification of the expressions given in Delaunay's Lunar Theory by a direct differentiation and substitution in the differential equations. E. J. Stone.

On the distribution of temperature in the transit-circle room at the Royal Observatory, Greenwich. H. H. Turner.

On the construction of a 5-foot equatorial reflecting telescope. A. A. Common.

1892.

Jan. 8. Re-appearance of *Saturn's* ring, and position-angle before the disappearance, observed at the Observatory, Utrecht. Professor J. C. Oudemans.

Observations of occultations of faint stars during the total eclipse of the Moon on 1891 Nov. 15. Communicated by Dr. D. Gill.

On the observations for coincidence of the collimators through the cube of the transit-circle at the Royal Observatory, Greenwich. H. H. Turner.

On the phenomena of the transit of the first satellite of *Jupiter*, and observations of the red spots on the planet. E. E. Barnard.

Observations of the phenomena of *Jupiter's* satellites, &c., in 1891, made at Mr. E. Crossley's Observatory, Bermerside, Halifax. J. Gledhill.

On the dynamics of the Earth's rotation with respect to the periodic variations of latitude. Professor S. Newcomb.

Observations of the total eclipse of the Moon, 1891 Nov. 15, at Edinburgh. Dr. R. Copeland.

A new photographic photometer for determining star-magnitudes. W. E. Wilson.

Observations of double stars, made at Mr. E. Crossley's Observatory, Bermerside, Halifax. J. Gledhill.

Jan. 8. The red stars in the great *Perseus* clusters. Rev. T. E. Espin.

On the investigation of the division errors of the scales of the Repsold measuring apparatus at the Cape Observatory, and the determination of the errors of the Oxford *réseau*. Dr. D. Gill.

Ephemerides of the satellites of *Saturn*, 1891–92 (continued). A. Marth.

On the relation between diameter of image, duration of exposure, and brightness of object in photographs of stars taken at the Royal Observatory, Greenwich. W. H. M. Christie.

Observations of occultations of stars by the Moon and of phenomena of *Jupiter's* satellites, made at the Royal Observatory, Greenwich, in the year 1891. Communicated by the Astronomer Royal.

Note on some values of the Sun's mean horizontal parallax which have been deduced from the Transit of *Venus* observations made in 1882. E. J. Stone.

Ephemeris of *Juno* near the time of opposition, 1891, from the corrected elements published in *Monthly Notices*, vol. l. page 495. Communicated by the Superintendent of the *Nautical Almanac*.

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ADDRESS

Delivered by the President, Lieut.-Gen. J. F. Tennant, on presenting the Gold Medal to Professor G. H. Darwin.

The Council has this year awarded the Gold Medal of the Society to Professor G. H. Darwin "for his work on Tides and their influence on the Figures and Motions of the Heavenly Bodies," and I have now to lay before you the grounds on which this award has been made.

It is some fifteen years since Professor Darwin commenced his researches into the history of the Solar System, and the striking character of some of his results has already modified so fundamentally our ideas of the course of planetary evolution that it may be well to recur for a few moments to the state of our existing knowledge before these investigations were undertaken. And fortunately Professor Darwin has left on record * a general but explicit statement of the problem or problems which presented themselves to his mind at a time (1877) when he was almost deterred from attempting their solution by the profundity of the mathematical difficulties involved. Looking back with him to this time, we may well admire the determination which has so persistently overcome not only these difficulties, but that of incessant personal ill-health. The Society is glad to welcome as its Medallist one so worthy the name of Darwin as to have worked, under circumstances where most men's energies would have flagged, at the theory of Planetary Evolution.

"The Nebular Hypothesis," to quote the words of our Medallist in 1877, "seems to contain no explanation of the diversity which the telescope shows us is to be found in the inclinations of planets to their orbits," for as the planets "were originally parts of the great solar nebula, there appears to be no reason why the axes about which they rotated should not be nearly parallel to the axis of rotation of the Sun." The explanation of the large inclinations of planetary axes must, therefore, be sought in some feature of their history not considered in the Nebular Hypothesis as far as it was developed by Laplace. It is this second chapter in the hypothesis which Professor Darwin's work supplies, though others doubtless remain to be written.

* *Phil. Mag.*, 1877 March; *Observatory*, vol. i., p. 13.

His first tentative suggestion for the origin of large obliquities was as follows:—The contraction of a rotating planet, from the nebulous stage downwards, involves an increase in the angular rotation, and thus a greater equatorial bulging. Now, the phenomena of precession depend on the attraction of the Sun, and of satellites on the equatorial protuberance and on the rotation; and if these latter are both increased as above, the obliquity of the axis will increase. The obliquity is, in fact, for a given planetary system, dependent merely upon the density, and has increased as the planet has consolidated from a nebula into a compact mass. The mathematical expression of this fact is

$$\text{Log tan (obliquity)} = A - \frac{B}{\text{density}},$$

where A and B are two constants depending on the particular planetary system.

In recent times, therefore, even long before the geological epoch, the obliquity of the Earth's equator to the ecliptic cannot have seriously changed, for its mean density has remained nearly constant. A possible reason for qualifying this statement had been already * examined by Professor Darwin, and found insufficient—viz, that geological changes, such as the elevation of continents, do not conform to the law of contraction by cooling above considered. In the deduction of the above law connecting obliquity and density, the surface of the contracting spheroid has been assumed to be one of equilibrium; but when the Earth has so far contracted as to reach the geological epoch, the surface begins to wrinkle into continents and oceans, mountains and valleys. Professor Darwin's first important paper on planetary history had been devoted to the investigation of the influence of such changes on the Earth's axis of rotation, and though the paper has many other points of interest, it cannot now be referred to further than to quote the principal conclusion in the author's own words: † "If a chain of mountains or a tableland, many degrees in width and as high as the Himalayas, were to be slowly elevated all round the equator, the effect would be *pro tanto* the same as an increase in the compression of the earth—that is to say, to increase the obliquity of the ecliptic. Nevertheless, the effect in that direction of even so gigantic a change would merely be to cause the Arctic circles to approach the tropics by a few inches. As, then, such an elevation is far in excess of any which geology teaches us can have ever taken place, we are compelled to believe that the obliquity of the ecliptic has remained sensibly constant throughout geological history," as it would if the surface had remained one of equilibrium.

We can thus infer from the above formula and our present

* *Phil. Trans.*, 1877, part i. † *Obs.*, vol. i., p. 15.

knowledge of the obliquity of the axis and density of the earth what was the obliquity when its density was half or a tenth of the present, or when the matter composing the earth was more diffused still. But there are two difficulties. Firstly, the above formula was deduced by arguments applicable to the precession of rigid bodies; and it yet remains to examine how far it will apply on reaching a stage in the past history when the planets were fluid or nebulous. Secondly, as we follow the history backwards, and the earth increases in size with diminution of density, there comes a stage when its surface reaches the Moon; and after this the two must be considered as one body. Before this the precessional effects will depend on the Sun and Moon conjointly, but after this on the Sun alone, and there is thus a discontinuity in the solution of the problem. But "in making a numerical application to the case of the Earth, it is found that the change in the obliquity must have proceeded so very slowly that even *when the earth was so diffuse as to fill the lunar orbit* the obliquity of the ecliptic must have had nearly its present amount." * Pushing back the argument beyond this point (which is characterised by the author as a somewhat wild speculation) it is found that when the Earth's diameter was a thousand times as great as it is at present, the obliquity was only a few minutes of arc.

Attention is called to the phrase printed above in italics because the conditions under which the Moon separated from the Earth were subsequently found by Professor Darwin to be so different; and I shall presently have to refer to this point as one of the most important results in his work.

Returning now to the history of changes in obliquity, and having disposed of the difficulty about the satellites of the other planets in a manner similar to that for the Moon and Earth, the question remains how far the formula for a rigid body is applicable to the history of non-rigid bodies. If it be applicable, then a study of the constants involved shows that the obliquities of the planets should decrease with distance from the Sun, which is not supported by observed facts; and it is thus probable that on taking account of the want of rigidity, fluidity, or nebulosity of a planetary mass we should find a different general result. The continuous alterations in form to which the yielding matter composing the planet would be subjected by the attraction of external bodies may be called bodily tides; and the problem may be regarded as the study of tides in the most general sense of the word. To this extension of our knowledge of planetary history beyond the limitation to the case of rigid bodies Professor Darwin has accordingly applied himself, with a success which the Council of the Society recognises in the present award, and which I will endeavour to describe to you.

The history of a planetary system may be traced in either

* *Obs.*, vol. i., p. 16.

direction, forwards or backwards in time. We may commence with a rotating and slowly contracting nebula, examine the conditions of its stability, and those under which a ring or satellite will detach itself when the stability breaks down, and follow the changes of the multiple system under the influence of gravitation. This is no doubt the ideal method of considering the question. But the generality of this problem, and the mathematical difficulties of dealing with fluids and gases, place it beyond the range of possible solution in practice. Professor Darwin has, however, recently considered * a particular case of the problem from this point of view—viz., that of a rotating fluid ellipsoid which becomes so elongated as to be unstable.

The other method of considering planetary history is to take an existing system, such as that of the Earth and the Moon, and trace its history backward. This has two great practical advantages. Firstly, although, as we have seen, perfect rigidity is inadmissible, the bodies can be treated as approximately rigid, which simplifies enormously the mathematical formulæ involved; and secondly, the general case can be at any time limited by the insertion of known numerical values for the arbitrary constants which present themselves. In this latter connection it is obviously advantageous to select as our particular case that of the Earth and Moon, where we have a far more complete knowledge of the numerical constants than in the case of other planets. Even in this instance, however, our knowledge is found to be lamentably deficient. Professor Darwin is often compelled to be content with a rough and even avowedly faulty assumption in the absence of numerical data, and accordingly some of his conclusions must be received with caution until these deficiencies can be supplied; and although his results have been occasionally quoted in an absolute form which he would be the first to disapprove, a reference to the original papers will always show clearly how far such general statements must be qualified.

If, in what follows, similar omissions of the necessary qualifications are occasionally found, the necessary brevity of this summary must be the excuse.

The work of our Medallist in solving the problem here indicated is to be found chiefly in five memoirs read to the Royal Society:

(1) "On the Bodily Tides of Viscous and Semi-elastic Spheroids, and on the Ocean Tides upon a yielding Nucleus." †

(2) "On the Precession of a Viscous Spheroid, and on the Remote History of the Earth." ‡

(3) "Problems connected with the Tides of a Viscous Spheroid." §

* *Phil. Trans.*, 1887, and *Proc. R. S.*, 1886.

† *Phil. Trans.*, 1879, pt. i. ‡ *Ibid.*, 1879, pt. ii.

§ *Ibid.*, 1879, pt. ii.

(4) "On the Secular Changes in the Elements of the Orbit of a Satellite revolving about a tidally distorted Planet." *

(5) "On the Tidal Friction of a Planet attended by several Satellites, and on the Evolution of the Solar System." †

The first of these papers, "A necessary first chapter to the investigation of the precession of imperfectly elastic spheroids," deals with the forced oscillations, first of a viscous, and ultimately of an elastico-viscous sphere. Sir W. Thomson had already treated the problem of a perfectly elastic sphere, and Professor Darwin shows how his solution may be extended to the case of a viscous sphere, and next of a sphere whose elasticity is not perfect but breaks down under continued stress, the forces requisite to maintain the body in any strained configuration diminishing in geometrical progression as the time increases in arithmetical progression. As an illustration of the necessity for caution in accepting the conclusions, I may quote Professor Darwin's words as to this assumption made at the very outset of the investigation. "There can be no doubt that all bodies *do* possess an imperfection in their elasticity of this general nature, but the exact law here assumed has not, as far as I am aware, any experimental justification; its adoption was rather due to mathematical necessities than to any other reason." If, then, we admit this assumption, it is shown how the problem in an imperfectly elastic sphere may be deduced from that in an elastic sphere. I need not further dwell upon the form of the solution, but a result obtained incidentally in the course of the work is of considerable practical interest. The author digresses from the main problem to consider the *ocean* tides on a nucleus such as we have considered. If there were two bodies precisely similar in form to the Earth, one of which was absolutely rigid except for the water on its surface, and the other composed of yielding matter, the apparent tides on these two bodies would differ, although the shape of the actual surface of the ocean on both might conceivably be the same, for the apparent tide in the first would be measured by the total displacement of the water, while in the second it would be the difference between the displacements of the water and the land. The failure of the observed ocean tides to agree with their theoretical values for a rigid nucleus will thus give an indication of the want of rigidity of the Earth's nucleus; and by a numerical interpretation of his equations Professor Darwin finds that unless the viscosity of the Earth were very much larger than that of pitch at near the freezing point, when it is hard, apparently solid and brittle, the viscous sphere would comport itself sensibly like a perfect fluid, and the ocean tides would be quite insignificant. It follows, therefore, that no very considerable

* *Phil. Trans.*, 1880, pt. ii. † *Ibid.*, 1881, pt. ii.

portion of the interior of the Earth can even distantly approach the fluid state.*

This conclusion as to the great rigidity of the Earth is confirmed several times in the course of Professor Darwin's work, and especially in a paper read to the Royal Society in 1881, "On the Stresses caused in the Interior of the earth by the Weight of Continents and Mountains,"† of which only the principal conclusion can here be quoted—that "if the Earth be solid throughout, then at a thousand miles from the surface the material must be strong as granite. If it be fluid or gaseous inside, and the crust a thousand miles thick, that crust must be stronger than granite, and if only two or three hundred miles in thickness, much stronger than granite."‡ Again, in the second paper quoted above, to which reference will immediately be made, another confirmation is deduced from the theory of the tides. It had been pointed out some twenty years before by Adams and Delaunay that there was an outstanding secular acceleration of the Moon's mean motion of some 3″ per century which could not be explained by ordinary lunar theory. It was suggested that the effects of *ocean* tidal friction might be responsible for this acceleration. The idea of friction of the ocean as held back by the Moon, against the solid Earth rotating inside it, was already familiar; as also the theoretical consequence that the reaction on the Moon would produce an apparent acceleration of the mean motion. It remained for Professor Darwin to point out that if the Earth were not very nearly rigid, an analogous tidal effect throughout its mass would produce a very much greater outstanding secular acceleration than that actually observed, whether the Earth be assumed viscous or very nearly perfectly elastic. Lastly, in the Memoir numbered (4) it is shown to be probable that, if we trace the Earth-Moon system backwards towards the point of separation, the original lunar orbit will make a considerable angle with the plane of rotation of the primæval planet, unless the Earth's viscosity be very large.

These four independent investigations thus point to the same conclusion—that the Earth must be enormously stiff; and are strongly confirmatory of Sir William Thomson's view that the Earth is solid throughout.

I pass now to the principal investigation of the second Memoir, in which a new light is thrown on the possibilities of planetary evolution. We have seen how, in 1877, Professor Darwin contemplated the separation of the Moon from the Earth at a time when the Earth was so diffuse as to nearly fill the present lunar orbit; and the subsequent history would have represented the contraction of the Earth and Moon to their present dimensions, their centres of gravity remaining at

* See also *B.A. Report*, 1883.
† *Phil. Trans.*, 1882, pt. i., p. 187. ‡ *Ibid.*, p. 230.

approximately the same mean distance. As I have already remarked, the notion of progressive change in this mean distance, due to the tides raised in one body by the other, was already familiar. It was reserved for our Medallist to show that when the term "*tide*" was extended to include yieldings of the whole mass of either body, the tidal action might be so great as to completely alter the above history. It is shown to be probable that the Moon was detached from the Earth when the latter had contracted to nearly its present dimensions, and that the present magnitude of the lunar orbit is a direct result of tidal interaction. By a very elegant geometrical illustration Professor Darwin has shown in two subsidiary papers* how the history of a system such as that of the Earth and Moon may be traced in its essential features without any reference to actual time. The notion of time is introduced when we assign a law or a numerical value to the viscosity of either planet; but if, without doing this, we recognise that the total energy of such a system must degrade, the chronological order of events becomes apparent, though the lapse of time between successive events is unknown. Initially the two bodies are rotating as a rigid body: the day and the month are the same; the Earth always turns the same face to the Moon and the Moon to the Earth; and they are nearly, if not quite, in juxtaposition. This configuration, however, being one of maximum energy, is essentially unstable, and the two bodies would gradually separate, the rotations of both being retarded, but that of the smaller much more rapidly than that of the larger. Under certain conditions, indeed, the diminution of rotation of the smaller might so far keep pace with its recession that the habit of always turning the same face to it might be sensibly retained throughout; and in the case of our Moon this habit was probably acquired very early in the history of the Earth. But with the parent body it would be different. The tides raised in it by the gradually receding satellite would indeed retard its rotation; but for some time the enlarging of the orbit of the satellite would increase its period of revolution much more rapidly, so that the number of days in a month (adopting the specific terms of our own system) would increase from the initial unity. But not indefinitely. After reaching a maximum, they would again diminish to unity, and we should ultimately reach a stage when the Earth and Moon were rotating as a rigid body, but at a considerable distance from each other. The tidal interaction of the two would be exhausted, and the configuration would be now one of minimum energy, and therefore stable. From this point their history would be concerned with the action of the Sun and other external bodies.

* "The Determination of the Secular Effects of Tidal Friction by a Graphical Method," *Proc. R. S.*, 1879; and "On the Analytical Expressions which gave the History of a Fluid Planet of Small Viscosity attended by a Single Satellite," *Proc. R. S.*, 1880.

In the geometrical construction above referred to Professor Darwin shows how these two limiting configurations are determined by the solution of the biquadratic equation

$$x^4 - hx^3 + 1 = 0,$$

which cannot have more than two real roots. In the simplest case of the problem, when the satellite is taken to be a point revolving in an orbit perpendicular to the axis of rotation of the planet, the equation appears at once; and in the more general case the expression on the left also occurs as the denominator in various integrals involved. The equation was originally obtained by seeking the condition that the Moon should always turn the same face to the Earth; but its fundamental significance is better represented by considering it as the condition that the energy of the system should be a maximum or minimum.

Now, in Memoir No. (2) of the five quoted above, Professor Darwin undertakes to trace the history of the Earth-Moon system backwards from its present configuration towards that of maximum energy on the hypothesis of a viscous Earth, and he obtains the surprising result that the internal tidal friction of such a viscous Earth would be sufficient to explain the present recession of the Moon, supposing it to have been separated from an Earth of nearly the present dimensions. He calculated the law of change of the day, the month, and the Moon's mean distance at the present time, and thus reduced previous concomitant values of the day, the month, and the Moon's mean distance. He finds that the number of days in a month, after increasing slightly for a time, diminishes as we go backwards (for one of the most interesting subsidiary results of the Memoir under consideration is that our Earth and Moon have at the present time passed through that configuration referred to above, when the number of days in a month is a maximum), and at the same time the distance of the Moon decreases. But the important point discovered by Professor Darwin is that when the day is as long as the month the Moon has nearly reached the surface of the Earth as we know it. The following table shows the course of the changes as we look backward from the present time:—

Time in millions of years.	Sidereal day in M.S. hours.	Moon's sidereal period in M.S. days.	No. of days in month.	Moon's distance in Earth's mean radii.
	h	d		
0·00	23·93	27·32	27·40	60·4
46·30	15·50	18·62	28·83	46·8
56·60	9·92	8·17	19·77	27·0
56·80	7·83	3·59	11·01	15·6
56·81	6·75	1·58	5·62	9·0
...	5·60	0·23	1·00	1·5

The whole of these results, excepting those in the last line, are derived from an integration by quadratures, on the hypothesis of a certain degree of viscosity of the Earth's mass. That degree of viscosity was so chosen as to be competent to produce the change of configuration in about the shortest possible times. Thus the time-scale in the first column must be regarded as a scale of inferior limits. It might be supposed from an inspection of this table that the changes took place at an ever-increasing rate as we look more and more remotely into the past, but this is not the case: for we finally come to a time when the changes proceeded slowly. The degree of retardation is, however, undetermined, and thus the length of the day when the month was equal to it can only be deduced from the equation of conservation of angular momentum, and this equation gives us no indication of the elapsed time.

"It is particularly important to notice that all the changes might have taken place in fifty-seven million years; and this is far within the time which physicists admit that the earth and moon may have existed. It is easy to suggest a great many *vera causa* for changes in the planetary system, but it is ingeneral correspondingly hard to show that they are competent to produce any marked effects without exorbitant demands on the efficiency of the causes and on lapse of time. It is a question of great interest to geologists to determine whether any part of these changes could have taken place during geological history," and on consideration this does not seem impossible.

Further, seeing that the results obtained point strongly to the conclusion that, if the Moon and Earth were ever molten viscous masses, then they once formed parts of a common mass, we are led to the inquiry as to how and why the planet broke up. "The conditions of stability of rotating masses of fluid are unfortunately unknown, and it is therefore impossible to do more than speculate on the subject. The most obvious explanation is similar to that given in Laplace's nebular hypothesis, namely, that the planet, being partly or wholly fluid, contracted, and thus rotated faster and faster until the ellipticity became so great that the equilibrium was unstable, and then an equatorial ring separated itself, and the ring finally conglomerated into a satellite. This theory, however, presents an important difference from the nebular hypothesis, in as far as that the ring was not left behind 240,000 miles away from the Earth when the planet was a rare gas, but that it was shed only 4,000 or 5,000 miles from the present surface of the Earth when the planet was perhaps partly solid and partly fluid. This view is to some extent confirmed by the ring of *Saturn*, which would thus be a satellite in the course of formation. It appears to me, however, that there is a good deal of difficulty in the acceptance of this view when it is considered along with the numerical results of the previous investigation." The chief difficulty is the smallness of the angular velocity indicated for the Earth at the time of rupture. "It seems

improbable that a rotation in a little over 5^h, with an ellipticity of one-twelfth " (very little in excess of that of *Jupiter*) " would render the system unstable."

Professor Darwin is thus led to a very ingenious suggestion as to the cause of rupture—viz., that the natural period of oscillation of the spheroid might be nearly coincident with that of the solar semi-diurnal tide, which would thus acquire a very large amplitude according to the elementary theory of vibrations. " Sir William Thomson has shown that a fluid spheroid of the same mean density as the Earth would perform a complete gravitational oscillation in $1^h\ 34^m$. The speed of oscillation varies as the square root of the density; hence it follows that a less dense spheroid would oscillate more slowly, and therefore a spheroid of the same mean density as the Earth, but consisting of a dense nucleus and a rarer surface, would probably oscillate in a longer time than $1^h\ 34^m$." *

It seems that tidal action may therefore have been responsible not only for much of the history of the Earth and Moon from their separation till the present time, but even for the separation itself, and it is hardly necessary to point out how great a modification of the Nebular Hypothesis this involves. I must again call your attention to the fact that large assumptions were made at the outset of these calculations. It was assumed that the Earth is homogeneous and viscous, and has a certain degree of viscosity, such that with the present length of day the semi-diurnal tide lags by $17° 30'$, which particular value makes the rate of change of obliquity nearly a maximum. Further, it was assumed that this viscosity remained constant as we trace the history of the Earth backward. Part of the calculations were repeated on a supposition of variable viscosity, and no serious modification of the results was found, which is so far satisfactory; and there are several instances in the investigations where the nature of the original hypothesis is found to have unexpectedly little influence on the results. Professor Darwin remarks that " whatever may be thought of the theory of the viscosity of the Earth and of the large speculations to which it has given rise, the fact remains that all the effects which have been attributed to the action of bodily tides would also follow, though probably at a somewhat less rapid rate, from the influence of ocean tides upon a rigid nucleus." This unimportance of the original hypothesis, indeed, almost seems to be characteristic of the whole subject, and no better illustration of it could be given than a conclusion of Sir William Thomson, several times quoted by Professor Darwin,† that the precession of a fluid spheroid would sensibly follow the same laws as though it were rigid. And we have already quoted the fact that the hypothesis of viscosity and nearly perfect elasti-

* *Phil. Trans.*, 1879, pt. ii., p. 537.

† See *Obs.*, vol. i., and Address to Section A, British Association, Glasgow, September 1876. The precession of a fluid spheroid has been ably treated by Mr. Bryan in a paper in the *Phil. Trans.* for 1889.

city of the earth would equally well explain the *amount* of the lunar secular acceleration, though in totally different ways.

In a later Memoir (No. (4) of the above series) Professor Darwin is led to modify his view of the initial state of the Earth-Moon system. In the table given above the effects of solar tidal friction have been practically neglected soon after leaving the present configuration. For as we go backwards the approach of the Moon to the Earth would produce a rapid increase of the lunar tides with reference to the solar. But as we approach the limiting configuration it is obvious that, though the tides raised in each body are large, the mutual tidal friction becomes small and ultimately vanishes when the two bodies rotate as a rigid body. The solar tidal friction can, therefore, not be neglected near this limiting configuration. On examination it is found that the effects of the solar tide would be slight save at the most remote period. On the whole, the effect of tidal friction would be to retard (looking backwards) the coincidence of the month and day, so that they would not reach equality until each was reduced to about 2 or $2\frac{1}{2}$ hours instead of $5^h\ 36^m$, and the surfaces of the two bodies would be nearly in contact, instead of there being even the small separation shown in the last line of the table. "Now it is a remarkable fact that the most rapid rate of revolution of a mass of fluid of the same mean density as the Earth, which is consistent with an ellipsoidal form of equilibrium, is $2^h\ 24^m$. Is this a mere coincidence, or does it not rather point to the break-up of the primæval planet into two masses in consequence of a too rapid rotation?"*

In this Memoir he also develops the general theory of the secular changes in the elements of the orbit of a satellite—that is to say, those elements which contain a description of the nature of the orbit; the mean distance, inclination, and eccentricity. It was remarked early in this Address that Professor Darwin's attention seems to have been originally attracted by the varied obliquities of the planetary axes to the ecliptic, and the whole of his work may be regarded as in a measure directed towards the quantitative explanation of these. In the paper on "Precession" he traced the changes in the obliquity of the Earth's axis sympathetic with those in the day, the month, and the distance of the Moon. But there the Moon's orbit was assumed to be circular and confined to the ecliptic. The introduction of eccentricity and inclination of the lunar orbit is found to modify the results of the former Memoir, and I have accordingly not referred to them. In the more complete discussion of Memoir (4) the changes in the inclinations (neglecting the eccentricity) of the lunar orbit are first followed backwards from the present configuration on two hypotheses—one that the viscosity is small, and the other that it is large. It has already been remarked that on the former supposition, when the day

* *Phil. Trans.*, 1880, pt. ii., p. 835.

and month are identical, we find the lunar orbit inclined at a considerable angle to the ecliptic; and in this case it would be difficult to believe that the Moon is a portion of the primæval planet detached by rapid rotation or by other causes. But by supposing the viscosity large enough, "we can trace the system back until the lunar orbit is sensibly coincident with the equator, and the equator is inclined to the ecliptic at an angle of 11° or 12°."* Next, the inclination of the lunar orbit is neglected for the study of changes in the eccentricity, and as an illustration of the interesting nature of such investigations I may quote one of the results obtained incidentally:†

"In the history of a satellite revolving about a planet of small viscosity, the circular orbit is dynamically unstable until 11 months of the satellite have become longer than 18 days of the planet. Since the day and month start from equality and end in equality, it follows that the eccentricity will rise to a maximum and ultimately diminish again."

Combining the two investigations, Professor Darwin shows how the history of the Earth-Moon system may be sketched from our present knowledge and the supposition that they originally formed part of the same planet.

"We begin with a planet not very much more than 8,000 miles in diameter, and probably partly solid, partly fluid, and partly gaseous. This planet is rotating in a period of from 2 to 4 hours about an axis inclined at about 11° or 12° to the normal to the ecliptic" (or even less if we include the effects of solar tidal friction; so that there is nothing extravagant in the supposition that it originally formed part of the Sun), "and is revolving about the Sun with a period not very much shorter than our present year." ‡ The planet separates into two masses, owing to rotational instability or tidal action, the larger being the Earth, and the smaller the Moon: they are nearly in contact with one another, and rotating nearly as though they were parts of one rigid body. The attraction of each distorts the other, and the Sun raises tides in both. In consequence of frictional resistance such a system is dynamically unstable. The Moon probably revolved a little slower than the Earth rotates—*i.e.*, the month was a little longer than the day—and this excess would tend to increase. Also "the axial rotation of the Moon is retarded by the attraction of the Earth on the tides raised in the Moon, and this retardation takes place at a far greater rate than the similar retardation of the Earth's rotation. As soon as the Moon rotates round her axis with twice the angular velocity with which she revolves in her orbit, the position of her axis of rotation (parallel with the Earth's axis) becomes dynamically unstable. The obliquity of the lunar equator to the plane of the orbit increases, attains a maximum, and then

* *Phil. Trans.*, 1880, pt. ii., p. 874.
† *Ibid.*, p. 877. ‡ *Ibid.*, p. 879.

diminishes. Meanwhile the lunar axial rotation is being reduced towards identity with the orbital motion.

"Finally her equator is nearly coincident with the plane of her orbit, and the attraction of the Earth on a tide which degenerates into a permanent ellipticity of the lunar equator causes her always to show the same face to the Earth."

As the month increased the lunar orbit became eccentric, and the eccentricity (never probably large) would reach a maximum and then continually decrease if the viscosity had remained unchanged; but as the Earth became more rigid and oceans with tides were formed, the decrease of eccentricity would gradually cease, and then again increase.

The plane of the lunar orbit is at first identical with that of the equator; but as the Moon recedes from the Earth the Sun's action is felt. Consequently the inclinations of the lunar orbit and equator to their proper planes increase to maximum values, and then decrease. Meanwhile these reference planes, which originally nearly coincided with the equator, open out, the inclination of the lunar proper plane to the ecliptic diminishing, while that of the terrestrial equator increases; and gradually the system arrives at its present state after an estimated period of fifty-four million years.

Professor Darwin thinks it hardly too much to say that if only sufficient time be granted for the process, and it be admitted that the diffused matter in the universe produces no material change in the motions of the Earth and Moon during the period of evolution, then some such system as ours must have been developed from a primæval planet, though the process might vary in detail. He says finally:—

"A theory, reposing on *veræ causæ*, which brings into quantitative correlation the lengths of the present day and month, the obliquity of the ecliptic, and the inclination and eccentricity of the lunar orbit, must, I think, have strong claims to acceptance."

Before passing from the study of the particular system which has most interest for us, and which, as we shall presently see, there is reason for believing to be unique in the solar system—that of the Earth and Moon—to the other planetary systems, attention may be briefly directed to the results of the third Memoir of the series, to which reference has not yet been made. In this several problems are discussed which suggest themselves in the course of the main investigation, but do not affect the main argument. The first of these is the distortion of the spheroid when it is subjected to tidal stress throughout its mass. "There is an unequal distribution of the tidal frictional couple in various latitudes. We may see in a general way that the tidal protuberance is principally equatorial, and that accordingly the Moon tends to retard the diurnal rotation of the equatorial portions of the sphere more rapidly than that of the polar regions. Hence the polar regions tend to outstrip the equator, and there is a

slow motion from west to east relatively to the equator." * But a numerical examination shows that no sensible effect of this kind can have occurred within recent geological times, although it may have been once sensible. It has had little or nothing to do with the observed crumpling of strata, but it may afford a possible explanation of the north and south trend of our great continents.

The second problem considered is that of the generation of heat by tidal friction. The kinetic energy lost by degradation must reappear as heat, which would have to be added to that due to the slow contraction of the Earth in any investigation as to its secular cooling. Numerical calculation, however, shows that the heat generated would be fairly represented by a temperature gradient from the surface downwards of about 1° Fahrenheit in 2,600 feet, whereas the observed temperature gradient, though very variable, is far greater: so that the effects of tidal friction are completely masked by those of contraction, and "Sir W. Thomson's investigation of the secular cooling of the Earth is not sensibly affected by these considerations." †

The third problem treats of the effects of inertia on the tides of a viscous spheroid, which have previously been shown to be unimportant for the purposes of the present inquiry.

In the fifth Memoir Professor Darwin passes from the Earth-Moon system to the other planets in detail. He has already made brief references to them in the fourth Memoir, pointing out how the small planet *Mars* fulfils our expectations that it should be far advanced in its evolution by presenting the only case in the whole system where a satellite is moving faster than the primary rotates, which will be the ultimate fate of our Moon; for "after the Moon's orbital motion has been reduced to identity with that of the Earth's rotation, solar tidal friction will further reduce the Earth's angular velocity, the tidal reaction on the Moon will be reversed and the Moon's orbital velocity will increase, and her distance from the Earth will diminish. But since the Moon's mass is very large, the Moon must recede to an enormous distance from the Earth before this reversal will take place. Now the satellites of Mars are very small, and therefore they need only to recede a short distance from the planet before the reversal of tidal reaction." ‡

When, however, the effects of tidal friction on the evolution of other planetary systems are considered numerically, Professor Darwin finds the startling result that the case of the Earth and Moon is probably unique. The separation of other satellites from their primaries, and of the planets themselves from the Sun, probably occurred in the manner suggested in the Nebular Hypothesis, and which was always assumed to be applicable to the Earth and Moon before the effects of tidal friction were investigated -

* *Phil. Trans.*, 1879, pt. ii., p. 588. † *Ibid.*, p. 593.
‡ *Phil. Trans.*, 1880, pt. ii., p. 883.

that is to say, the present orbits of the satellites roughly indicate the sizes of the parent bodies at the time of separation. Retrospectively, it is comparatively easy to recognise the singular character of our own system. It is a link between the planets which (as far as we know at present) are unattended and those which have satellites; and we have seen reason for believing that the separation of the Moon from the Earth was possibly more or less of an accident, and due to extraneous causes, such as the near coincidence of two harmonic periods. The abnormal character of our satellite is also indicated by its large size in comparison with the parent body; and when we proceed to the comparison of the orbital momentum of the satellites with the rotational momentum of the parent body, we find a ratio of 4·78 for our own system, while it seems improbable that this ratio can exceed ·04 for *Saturn*, the most favourable case among the other planets. On using such approximate numerical data as are available, Professor Darwin concludes that it appears unlikely that the satellites of "*Mars*, *Jupiter*, and *Saturn* originated very much nearer the present surfaces of the planets than we now observe them. But the data being insufficient, we cannot feel sure that the alteration of the dimensions of the orbits of these satellites has not been considerable. It remains, however, nearly certain that they cannot have first originated almost in contact with the present surfaces of the planets, in the same way as, in previous papers, has been shown to be probable with regard to the Moon and the Earth."

Further, the progressive decrease in the number of satellites as we pass from the outer planets to the inner may be connected with the increasing efficiency of solar tidal friction as we approach the Sun. The detaching of a satellite from a contracting planetary mass is probably a result of the increase of rotational velocity due to contraction. Now, solar tidal friction tends to check the rotation of the planet. For the outer planets the solar tidal friction would be small, and not sufficient to seriously retard the increase of rotation due to contraction, so that one or more satellites would be shed at successive epochs of instability. But for the nearer planets the influence of solar tidal friction would be greater; and for the Earth there may have been "for a long time nearly a balance between the retardation due to solar tidal friction and the acceleration due to contraction, and it was not until the planetary mass had contracted to nearly its present dimensions that an epoch of instability could occur." For the planets within the Earth, *Mercury* and *Venus*, not only are the effects of solar tidal friction manifested by the absence of satellites, but we have more recent evidence in the observations of M. Schiaparelli that its work is now complete. If M. Schiaparelli's conclusions are correct, the great solar tides have reduced these planets to the condition of our own Moon, rotating in the period of revolution round the primary.

In giving this brief sketch of the main outlines of Professor Darwin's work much has been omitted, for obvious reasons, that is of interest and importance. If some of the conclusions should appear speculative, it must be borne in mind that the main argument is the unexpected result of a mathematical investigation, and not an original speculation supported by subsequent analysis. For this reason the ideas recorded by Professor Darwin in 1877 have been contrasted with the results of his principal Memoir on the history of the Earth and Moon. There is no doubt that he has been at times hampered by the lack of sufficient data, and at others has not been able to represent known facts in our limited mathematical analysis; but if these are drawbacks from the point of view of great accuracy in the conclusions, from another standpoint they are advantages as indicating the deficiencies which it is important to supply in the future. Professor Darwin has shown how there may be correlations between the viscosity of the Earth, the change of obliquity of the ecliptic, and the Moon's secular variation; between the configuration of planetary systems and the rigidity of the matter composing them. And he has thus indicated how, in the future, one department of astronomy may benefit by increase of knowledge in another; and he has added a new link between astronomy and physics, which may in the future mean new opportunities for both. Let us hope that the time for taking advantage of them may not be delayed by any fault of astronomers!

Let us now turn for a few moments to the more practical work of our Medallist, which is also specified in the award. He has proved himself on several occasions skilful in experiments more or less related to his theoretical investigations. The reports which (in conjunction with his brother, Mr. Horace Darwin) he has made to the British Association on the lunar disturbance of gravity record a series of ingenious and very delicate experiments, which, unfortunately, disturbing causes rendered useless. And, although the subjects of our Medallist's theoretical work are generally beyond the reach of laboratory experiments, yet in such papers as that "On the Formation of a Ripple-mark in Sand" (a passing glance at the diagrams in which will show how ingeniously and prettily the complex nature of the liquid vortices is made manifest) and "On the Horizontal Thrust of a Mass of Sand" (whose value was acknowledged by the award of a medal by the Institute of Civil Engineers), we recognise a relationship to the study of the wrinkling of the Earth's surface into continents, and the stresses caused in its interior by their weight.

But Professor Darwin has done practical work of a most useful kind in another sense. It has in recent years fallen to his lot to undertake most of the laborious work necessary for the practical study of the ocean tides. Fifty years ago, though the general phenomena were known and some examination made of tides in various parts of the world, yet it was mainly in European seas

that extensive series of observations were available or that any attempt had been made to deal with them adequately; but the methods were imperfect, and the reductions required the constant exercise of much skill. The great advance of our modern knowledge is mainly due to the energy of the British Association and its committees. Two Reports, in 1872 and 1876, chiefly due to Sir W. Thomson, may be considered the first important step towards an extensive study by harmonic analysis. All the phenomena now, instead of being referred to the Sun's and Moon's hour angles, declinations, and parallaxes, were considered as harmonic functions of angles varying uniformly with the time; the entire phenomenon was looked on as the sum of a number of harmonic undulations depending directly on the Sun's and Moon's mean hour angles and longitude, &c., which increase directly as the time. This great simplification has enabled work to be undertaken which would previously have been impossible.

In the Report for 1883 Professor Darwin devoted himself to the revision and development of the method of these two reports and the production of a manual for harmonic analysis. "A committee," he remarks, "appointed for the examination of the question of the harmonic analysis of tidal observations practically finds itself engaged in the reduction of Indian tidal observations, since it is only in that country that any extensive system of observation, with systematic publication of results, exists." The Indian work was till comparatively recently carried out by Major (now Lieut.-Colonel) Baird, R.E., and has consisted in the observation and discussion of the tides at a number of places on the Indian coasts for which tide tables are now annually published by the Indian Government.

Since then something has been done elsewhere; but if we consider the great amount which might be done, the result is lamentably small. Forms for reduction have been printed, with full directions, but apparently the cost of reduction is still so great as to deter most Governments from undertaking the work on any large scale; and it may be admitted that in many cases the scientific interest is of greater importance than the practical value of discussing very large series of observations.

Recognising the importance of this consideration, Professor Darwin has recently turned his attention to supplying such data as will suffice for sailors, to whom it is of importance to know the times and heights of high and low water at certain points near the entrances to ports. Unfortunately, excepting in the North Atlantic, where the diurnal tides are very small, such information is very scanty and inaccurate. "When there is a large diurnal inequality, as is commonly the case in other seas, the heights and intervals, after the upper and lower lunar transits, are widely different; the two halves of each lunation differ much in their characters, and the season of the year has great influence. . . . The tidal information supplied by the Admiralty for such places consists of rough means of the rise

and interval at springs and neaps, modified by the important warning that the tide is affected by diurnal inequality." Such information being almost useless, Professor Darwin devised an approximate but very cheap and simple method (described in the Bakerian Lecture at the Royal Society about a year ago) for predicting tides at any port after a very moderate amount of computation. He is, it is believed, at present occupied with the further simplification of this method by some mechanical contrivances, and we may sincerely hope that his efforts may be successful and lead to a great practical improvement in tide tables everywhere.

If it were generally known that for any port whose tidal constants are known the curves could be furnished for a very small cost, I cannot but think that many ports where tidal observations have been made would go to the expense of having them discussed, and that tide gauges would be established to make observations.

The President, then delivering the Medal to Professor Darwin, addressed him in the following terms:—

Professor Darwin, I have now to complete my duty here by delivering to you the medal which the Council have awarded. As your father taught us how the action of admitted laws would allow us to trace back all living nature to the first slight germs of life and thus account for the wonderful and beautiful diversity around us, so you, in your turn, have endeavoured to trace back the fabric of the world and solar system to its remote origin. Neither your subject nor the mode of investigation you have necessarily followed will admit of your work meeting with that general assent which almost at once greeted your father's, but we hope that this medal may serve to assure you that its value is appreciated, and encourage you to perfect the outlines and fill up the details of the sketch you have given to us. That you may have health and strength to continue your labours is the best we can wish you.

The meeting then proceeded to the election of the Officers and Council for the ensuing year, when the following Fellows were elected:—

President.

E. B. Knobel, Esq.

Vice-Presidents.

W. H. M. Christie, Esq., M.A., F.R.S., Astronomer Royal.
J. W. L. Glaisher, Esq., M.A., Sc.D., F.R.S.
E. J. Stone, Esq., M.A., F.R.S., Radcliffe Observer.
Lieut.-Gen. J. F. Tennant, C.I.E., R.E., F.R.S.

Treasurer.

A. A. Common, Esq., LL.D., F.R.S.

Secretaries.

E. W. Maunder, Esq.
H. H. Turner, Esq., M.A., B.Sc.

Foreign Secretary.

William Huggins, Esq., LL.D., D.C.L., F.R.S.

Council.

Captain W. de W. Abney, C.B., R.E., D.C.L, F.R.S.
Arthur Cayley, Esq., M.A., Sc.D., LL.D., D.C.L., F.R.S., Sadlerian Professor of Pure Mathematics, Cambridge.
Hon. Sir James Cockle, M.A., F.R.S.
A. M. W. Downing, Esq., M.A., Superintendent of the "Nautical Almanac."
George Knott, Esq., B.A., LL.B.
Frank McClean, Esq., M.A.
W. H. Maw, Esq.
W. E. Plummer, Esq., M.A.
A. Cowper Ranyard, Esq., M.A.
Isaac Roberts, Esq., F.R.S.
Rev. Walter Sidgreaves, S.J.
E. J. Spitta, Esq.